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The influence of cultivation technologies on the phytosanitary condition and productivity of spring wheat in the Central Non-Black Earth Region.

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ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ АВТОНОМНОЕ ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ ВЫСШЕГО ОБРАЗОВАНИЯ «РОССИЙСКИЙ УНИВЕРСИТЕТ ДРУЖБЫ НАРОДОВ ИМЕНИ ПАТРИСА ЛУМУМБЫ»

На правах рукописи

Саке Франсесс Сиа

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INTRODUCTION

Relevance of the research topic: Wheat (*Triticum aestivum* L.) is a globally significant staple cereal that is consumed in various forms, depending on regional preferences [1]. Its nutritional value, adaptability, and economic impact make it a crucial crop. However, challenges such as pests, climate change, and the need for sustainable farming practices necessitate adopting maintainable techniques to ensure its continued availability by 2050. Russia is a leading producer and exporter of wheat, accounting for the majority of wheat grain production. In 2020, the country produced 85.9 million tons of wheat, making it the second most important food crop, contributing nearly one-third of the total food grain production [2]. Wheat is a staple diet for more than 50% of the global population [3], with average per capita consumption ranging from 95 kg in advanced countries to 60 kilograms in tropical African nations [4].

Wheat cultivation dates back approximately 10,000 years to the Neolithic Revolution, with early varieties originating in the southeastern region of Turkey. Hexaploid bread wheat dominates global production, covering 95% of wheat-growing areas [5]. In 2019, wheat occupied 216 million hectares worldwide, accounting for 26% of total global cereal production [6]. Europe remains a leading wheat producer, with Russia, France, Germany, the UK, Ukraine, and Poland collectively contributing 71% of Europe’s production [7]. The region's wheat yield is 20% higher than in North America and Asia and 40–45% higher than in South America and Africa. It could be mainly due to increased wheat cultivation and the use of high-yield varieties [8]. Wheat is a raw ingredient used to produce bread, pasta, noodles, and pastries.

Its high content of essential amino acids, including protein, thiamine, and niacin, makes it particularly valuable for the baking industry. Additionally, wheat byproducts, such as bran and straw, serve as livestock feed [9]. The wheat crop is also vital for industrial purposes, including ethanol and starch production, as well as a protein source for vegetarians. In the beverage industry, wheat is used in the production of beer, whiskey, and vodka, while wheat germ oil is employed in pharmaceuticals for skin care due to its high vitamin E content [10]. Wheat research and extensive cultivation remain a priority due to their significance in food security, economic stability, and industrial applications. Hence, the application of appropriate fertilizers is crucial for increasing wheat yields to meet the growing demand. Nitrogen-based fertilizers, applied at the correct rates and times, significantly impact yield. Studies suggest that nitrogen application should occur 3 to 4 times during the growing cycle, using a split application technique of 20–60 kg ha^{-1} at critical growth stages [11, 12, 13, 14]. Conversely, [12, 14, 15] recommend applying 120 kg ha^{-1} of nitrogen in three phases: 25% at sowing, 50% at mid-tillering, and 25% at anthesis. However, the suitability of nitrogen sources such as NPK and urea under climate change remains uncertain. Recent studies indicate that *T. aestivum* has shown poor performance in many regions due to dry autumn weather. To counteract this, spring wheat should receive nitrogen fertilization early to enhance regeneration [16, 17, 18]. Applying ammonium nitrate or sulfate to frozen soil or using amide nitrogen through foliar feeding during stem elongation and grain filling can improve resilience against climatic stressors, increasing grain yield and seed index [10, 11, 14, 15, 19]. Research suggests that applying urea, ammonium nitrate, or ammonium sulfate at critical wheat growth stages enhances grain filling and protein content, contributing to overall yield improvement [20, 21, 22, 23, 24]. Micronutrient and macronutrient fertilizers, as well as crop protection chemicals, are essential for improving wheat grain yield and quality [25, 26, 27, 28; 29]. However, over half of the world's wheat-cultivating soils lack these essential nutrients, resulting in high soil pH and low calcium carbonate ($CaCO_3$) levels. $CaCO_3$ is critical in plant metabolism, including nutrient metabolism, photosynthesis, and hormone regulation. Its deficiency inhibits nutrient availability, emphasizing the importance of soil nutrition management [30, 31, 6].

Russia’s Chernozem soils, among the world's most fertile, provide ideal conditions for wheat cultivation [32]. However, historical changes in tillage practices have contributed to soil depletion. Wheat, like other cereals, is susceptible to aridity and nutrient deficiencies.

To increase wheat yield, quality, and profitability, as well as enhance wheat's resistance to diseases, crop protectionists, wheat producers, breeders, and policymakers should investigate and adopt optimal cultivation technologies. Therefore, this research evaluates the impact of various cultivation technologies on the yield and quality of spring wheat cultivars. It aims to identify practices that enhance productivity and assess the economic viability of these technologies by analyzing input costs, labor requirements, and market returns [32]. Additionally, it examines how various cultivation methods affect disease incidence and severity within an integrated disease management framework. The outcomes of this research will ultimately inform the selection of suitable cultivation techniques and wheat varieties that promote sustainable and resilient wheat production in diverse climatic conditions and under disease pressure. Therefore, this study is timely and highly relevant to modern wheat production and current farming practices [6]. The research stands out specifically due to the world's need for an integrative, innovative approach that optimizes crop yield and economic potential. It also aims to pinpoint disease-resistant varieties and technologies in the face of global food challenges, such as food insecurity, climatic variability, and constrained resources. The significance of this research lies in its goals, research questions, and innovative approach, designed to unravel the complex dynamics of the factors influencing spring wheat production and productivity. The current investigation aims to answer an essential question in modern wheat production systems: How can advanced cultivation technology promote sustainable wheat production? Given the pressures of increasing global demand and environmental constraints, it is imperative to explore sustainable cultivation practices that maximize yield quality and profitability. The study would assess the agronomic performance of two novel varieties and one landrace variety, as well as the economic feasibility of the different cultivation technologies used. It would also investigate which varieties could exhibit disease resistance under these various technologies, thereby directly contributing to the development of resilient agricultural practices that can meet these demands while lessening ecological effects. This study emphasizes the use of integrated wheat farming technology, including a hybrid spring wheat variety that improves yield, profitability, and disease resistance. [31].

Degree of development of the research study: Despite existing studies, the interactions between cultivation technologies, varietal characteristics, and their combined effects on disease resistance and economic efficiency remain insufficiently explored. This study addresses the lack of regionally adapted cultivation practices for new spring wheat varieties developed at the Federal State Budgetary Scientific Institution “Federal Scientific Center “Nemchinovka” (FSBSI “FSC”). This gap underscores the importance and necessity of further research to optimize cultivation techniques and enhance spring wheat's resilience in the face of growing climatic and food security challenges.

Purpose of the research: to study the regularities of improving the phytosanitary condition of spring wheat crops and increasing their productivity using various cultivation technologies in the conditions of the Central Non-Chernozem region.

Research objectives

1. To determine the effect of cultivation technologies with varying intensity of mineral fertilizers and the use of chemical plant protection products on the agronomic traits, yield, and grain quality of new spring wheat varieties.
2. To identify varietal differences in susceptibility to pathogens and responses to applied cultivation practices.
3. To study the effect of plant protection products used in combination of mineral fertilizers on the development and spread of fungal diseases in spring wheat crops.
4. To assess the economic efficiency of each cultivation technology for the cultivation of new spring wheat with different levels of intensity using mineral fertilizers and plant production products.

The objects of research are spring wheat varieties Beliana, Radmira, Agroos, fertilizers, and plant protection products.

The scientific novelty of the study:

The response of new spring wheat varieties bred at the Nemchinovka Research Center to zonal cultivation practices with varying intensity was studied. The promising Belyana and Agros varieties were found to exhibit high productivity under biotic stress factors in the field. High-intensity cultivation was shown to be effective in reducing the development of key fungal diseases in spring wheat crops, including Fusarium head blight (Fusarium sp.), Septoria leaf blight (*Zymoseptoria tritici),* and powdery mildew (*Blumeria graminis f. sp. tritici*). An assessment of the varieties' disease resistance revealed that Radmira shows high resistance to Fusarium head blight and powdery mildew, while Belyana shows high resistance to Septoria leaf blight. It has been established that high-intensity technology results in higher grain yields and net income, but intensive cultivation technology achieves the shortest payback period and the highest profitability. The new spring wheat variety, Belyana, has demonstrated the best economic performance.

Theoretical and practical significance of the research: The research results expand the theoretical understanding of the potential use of zonal cultivation technologies for spring wheat and reveal varietal differences in response to biotic stressors and agronomic practices. For the first time, the effectiveness of intensive and high-intensity cultivation technologies has been demonstrated in the Moscow region, particularly in terms of increasing productivity, reducing the incidence of major fungal diseases (Fusarium head blight, septoria leaf blotch, powdery mildew), and enhancing economic sustainability. Scientifically based recommendations have been developed for selecting varieties and cultivation technologies tailored to this region. The findings can be applied in most cereal production systems and incorporated into the agricultural and educational institutions for training specialists in agronomy, plant protection, and breeding.

Research methodology and methods. The study was conducted based on an analysis of domestic and international scientific literature, using widely accepted methods of fieldwork, laboratory testing, and economic analysis. The experimental work was conducted using approved methodologies to assess the agronomic efficiency of cultivation technologies, disease resistance of varieties, and the financial feasibility of implementing these technologies. The research applied principles of a systematic approach, comparative analysis, and statistical data processing.

Provisions submitted for the dissertation defense:

1. The influence of zonal cultivation technologies (intensive and high-intensive) on the productivity of spring wheat, including grain yield and quality, under the environmental conditions of the Moscow region and similar agroecological zones.
2. The effectiveness of cultivation technologies and wheat varieties in reducing the development of major fungal diseases: Fusarium head blight (Fusarium spp.), septoria leaf blotch (*Z. tritici*), and powdery mildew (*B. graminis* f. sp. *tritici*).
3. Varietal differences in susceptibility to pathogens and responsiveness to applied agronomic practices.
4. The economic efficiency of the application of the developed cultivation technologies was assessed based on indicators such as profitability, payback period, and break-even point.

Degree of reliability. The reliability of the obtained results is confirmed by conducting the research in accordance with generally accepted methodologies for field and laboratory testing, utilizing statistically sound data analysis methods, and maintaining proper documentation. The experimental data provide a solid foundation for the recommendations and conclusions intended for practical application, indicating a high level of research credibility.

Approbation of the work: The research results have been reported at three scientific conferences, including two international ones. Eleven scientific papers have been published based on the materials of the dissertation, including one in a publication included in the list of the Higher Attestation Commission of the Russian Federation, eight in international scientific journals indexed in the Scopus database, and two in other journals.

Personal contribution by the author. The dissertation was completed independently by the author. The author defined the research objectives and tasks, organized a three-year field experiment, collected, analyzed, and statistically processed the experimental data. Additionally, the author contributed to preparing publications on the research topic and compiling the dissertation materials.

Scope and structure of the dissertation. The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. It is 231 pages long and includes 32 tables and 23 figures. The work examines 341 relevant literature sources.

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CHAPTER ONE

Literature Review

1.1 Origin and distribution of wheat

Wheat generally refers to a group of cereal grass species belonging to the Triticum genus in the Poaceae family. *T. aestivum* L. is one of the cornerstone cereal crops that has significantly contributed to global food security for centuries [33, 34]. Understanding its center of origin and distribution is essential for unraveling the historical, genetic, cultural, and agricultural aspects of this crucial grain. Wheat's precise center of origin remains a subject of scientific inquiry and debate. However, historical evidence suggests that its roots can be traced back to the Fertile Crescent in the Middle East, a region encompassing parts of modern-day Iraq, Syria, Turkey, and Iran [35]. Many important cereal crops, such as winter and spring wheat, were domesticated in this area, which is frequently referred to as the "cradle of agriculture." These crops then disseminated to many regions globally, responding to a range of climates and habitats. In the end, human selection and cultivation methods, along with the availability of wild grasses with desired features, led to wheat becoming a distinct agricultural entity. From its roots in the Fertile Crescent, wheat has journeyed around the globe, adapting to varied environmental circumstances and evolving into numerous kinds. This evolution makes it an important crop in sustaining human populations and contributing to global food security [36]. The distribution has been affected by various variables, including climate, soil types, human migration, disease, and cultural preferences [35]. Today, wheat is grown on virtually every continent, albeit with varying levels of prevalence and importance in different regions [5, 37, 6]. Europe is one of the major centers for wheat cultivation. Countries like Russia, Ukraine, France, Germany, and the United Kingdom have extensive winter and spring wheat production due to favorable temperate climates and rich agricultural traditions and technologies [38]. The United States and Canada have significantly contributed to global wheat production. The Plains States in the U.S., referred to as the "Wheat Belt," have traditionally been significant wheat-producing regions. In Asia, winter and spring wheats are planted based on the production time, with considerable cultivation occurring in regions such as China and India. . China has a long history of wheat cultivation and is among the world's largest wheat producers [40, 41]. In Australia**,** notwithstanding its comparatively smaller landmass, the country is among large wheat producer, especially during the winter period, which is favorable for such a variety. The southern parts have a comparatively suitable climate for wheat cultivation [26, 42].

Wheat cultivation has also gained eminence, mainly in certain countries with suitable weather conditions, such as South America. Though not as widely cultivated in regions like Europe and North America, wheat plays a significant role in agricultural production in areas such as Argentina, Chile, Uruguay, and Brazil [43]. The African continent is not a major wheat region, though it has recently gained ground in wheat production. In Africa, preference is placed on other cereals such as rice and maize, which are key staple foods in these regions. However, Northern Africa, including Morocco and Egypt, has a historical involvement in wheat cultivation, particularly of winter wheat, due to their Mediterranean climate, which is conducive to these varieties during cooler months. As agricultural technologies evolved, initiatives focused on enhancing wheat production and local food security by introducing improved varieties and sustainable farming practices. These efforts have expanded its cultivation in African countries like Nigeria, Senegal, Mali, Sudan, Zambia, Zimbabwe, Malawi, Madagascar, and Mozambique. However, challenges like water availability, suitable soil, climate, and limited cultivation technology access are significant challenges to wheat cultivation [44, 45]. According to [46], Asia accounts for a considerable proportion of world wheat production, estimated at 44%, followed by Europe at 34% and the Americas at 15%, while Oceania contributes 3% and Africa around 4% (Fig. 1).

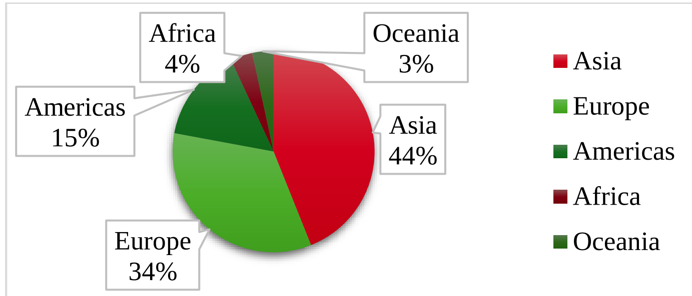


Figure 1. Production shares of wheat by region [46].

1.2 Factors enhancing wheat cultivation and distribution across the globe

1. Climate adaptation: Wheat's sensitivity to different climatic conditions has significantly constrained its global distribution.

2. Agricultural practices: Agricultural practices, such as seed exchange, trade, and the movement of people, facilitated the spread of wheat. Ancient trade routes and migration patterns were crucial in spreading wheat.

3. Cultural preferences: Cultural and dietary preferences influenced the distribution of wheat. In regions where wheat-based foods are integral to the diet, the cultivation and consumption of wheat have led to its prominence.

4. Modern breeding: Advancements in plant breeding have further expanded the distribution of wheat, especially the temperate-loving varieties. Developing high-yielding and disease-resistant cultivars has allowed wheat to be adapted to a broader range of environments. Global collaboration in research and sharing genetic resources has played a pivotal role in disseminating improved varieties to regions with diverse climatic conditions.

1.3 Importance of wheat

Wheat is one of the most essential grains worldwide, ranked second in production after rice [47, 48]. Global wheat production was estimated at approximately 216 million hectares of land in 2019, making it the second most abundant cereal crop, producing 749 million tons after maize [36]. According to [49], more lands are planted with wheat than with any other crop, making it the main cereal crop for human consumption worldwide. Wheat accounts for over 25% of global wheat output, making it a unique crop in terms of ensuring global food security by meeting roughly 20% of human carbohydrate and protein requirements [50].

Wheat is an important cereal crop since it is the primary source of food for more than 35% of the world's population [51, 52]. It gives more than 45% calories and 40% of protein [53, 6]. It is one of the most important and productive cereal species in the world. Its kernel has 12% water, 18% minerals, and 2.2% crude fibers. Wheat is the most extensively grown and recognized cereal in the world [45, 55]. It contains thiamin, riboflavin, niacin, and a small amount of vitamin A [54], making it the most widely cultivated and accepted cereal in the world [45, 55]. Due to its ability to thrive in diverse growing climatic conditions and widespread use, wheat holds immense global economic significance [6]. It is cultivated across the globe and serves as a staple food in numerous countries, contributing to the dietary needs of millions of people [47]. In addition to its direct use, wheat is an ingredient in numerous processed foods, including bread, pasta, pastries, semolina, noodles, biscuits, bulgur, couscous, cookies, malt, dextrose, alcohol, and breakfast cereals [37, 56]. Its versatility extends to non-food applications, including producing biofuels, animal feed, and industrial products like starch and gluten [57, 58, 59, 60, 51].

Wheat is a vital crop in the food industry, serving as a staple food for millions of people in many countries and a critical raw material for various industries. However, its production scale and economic importance extend far beyond this role. In Russia, wheat is a significant crop that helps the economy thrive and keeps people fed. In Africa, it is still an important part of trade and food security. Understanding the dynamics of wheat cultivation technologies, its biological characteristics, trade, and consumption in these regions is crucial for sustainable agricultural and economic development [61]. About 30% of Russia's spring wheat comes from areas close to Kazakhstan, such as the Volga, Urals, Krasnodar Krai, Rostov Oblast, Stavropol Krai, and Siberian Federal Districts. Spring wheat cultivation usually starts in late April. According to the Russian Ministry of Agriculture, as of May 2023, spring wheat was sown on 10.4 million hectares (m ha), lagging last year’s 13.1 m ha for the same period. The delay is particularly notable in crucial spring wheat areas, reflecting a year-over-year reduction of 1.5 m ha. The western regions are experiencing dry conditions, while the eastern areas face excessive moisture, resulting in challenging conditions for spring wheat cultivation and initial growth throughout Russia [62] Figure 2. Thus, the urgent need to formulate varying cultivation technologies amid these challenges should be a crucial focus of research.

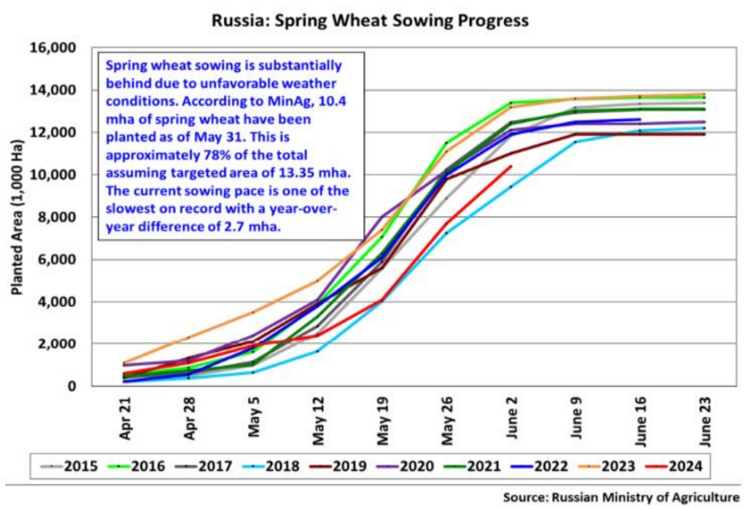


Figure 2. Spring wheat progresses [62]

1.4 Botanical and biological description of spring wheat

Six distinct biological species of *Triticum* wheat belong to two phylogenetic lineages cultivated globally. However, Winter wheat (*Triticum aestivum* L.), Spring wheat (*Triticum durum* L.), hard red and soft white (*T. durum*), and club wheat (*T. compactum*) are the most critical wheat varieties for food grain production and industrial use. Spring wheat is an annual grain crop from the *Poaceae* family, cultivated in temperate regions without the necessity for vernalization. The plant possesses a fibrous root system, a jointed hollow stem, and elongated, thin leaves with parallel venation. The inflorescence is a spike composed of several spikelets, each carrying 2–5 florets, which are predominantly self-pollinated. The reproductive phase encompasses blooming, pollination, and grain filling, culminating in the formation of starch- and protein-rich caryopsis. Spring wheat completes its life cycle in 90–120 days, with germination happening within a few days under optimal circumstances (10–25°C), and tillering commencing after the emergence of 3–4 leaves. The crop is deemed mature when the grains attain physiological maturity and is typically harvested at 12–14% moisture content for optimal processing and storage [61, 34].

1.5. Growth, development, and agronomic traits of spring wheat

Wheat undergoes distinct growth stages, each marked by physiological and morphological changes; it is worth noting that understanding its growth and development is essential. Agronomic traits refer to the characteristics of crops that impact the yield, quality, and ability to resist biotic and abiotic stresses. These traits include plant height, tillering capacity, root length, grain size and weight, and physiological ability to resist pests, diseases, and other environmental stressors. Agronomic traits are critical in improving wheat crop production [63]. Investigating agronomic traits and formulating novel cultivation strategies to enhance crop yield, quality, and resistance to pests and diseases is essential in wheat production [64]. While significant advancements in wheat grain yield have been achieved through breeding programs, it is crucial to integrate superior genotypes with enhanced agronomic technologies and physiological traits linked to high yield, derived from complementary and genetically diverse resources [65, 66, 67, 68]. Despite notable advancements in wheat production, yield levels remain relatively low and stagnant, primarily due to challenges such as erratic climate changes, disease incidence, and severity. Improving wheat production through diverse cultivation technologies and favorable genotype traits is crucial for addressing food security and feed requirements. Agronomic and growth characteristics, including plant height, harvest index (HI), total biomass, number of productive tillers, grain number per spike, spike length (SL), number of kernels per spike, thousand seed weight, and grain weight per spike, critically influence wheat grain yield and contribute to the enhancement of wheat quality [71, 73, 74, 75, 66, 65]. Hence, wheat producers need to understand the stages of wheat growth and development.

1.5.1. Vegetative traits

Understanding how a wheat plant grows is critical for advocating and implementing field management strategies to improve its sustainability and profitability [76, 77]. A plant's growth is separated into vegetative and reproductive stages, each having unique morphological traits and physiological activities. Vegetative stages begin from seeding emergence, the beginning of tillering, tillers formed, the beginning of erect growth, leaf sheath strongly erected, first node visible, second node visible, and combined with other factors, these traits can help farmers implement suitable management strategies to achieve more significant and sustainable yields [78, 79]. Thus, researchers and breeders must make informed decisions for farmers who manage several environmental factors to increase yield, such as sowing at the right time, maintaining adequate plant density, fertilizing the soil, and improving weed, pest, and disease control methods [80].

Germination and seedling establishment: Wheat seeds germinate when provided with adequate moisture, temperature, and oxygen. During this stage, the seed embryo undergoes cell division and elongation, giving rise to the primary root and shoot.

Tillering stage: As the plant matures, it produces additional shoots called tillers. The number of tillers formed influences the potential number of heads and grains per plant.

Stem elongation stage: During this phase, the stem elongates, accompanied by the emergence of more leaves. The development of the stem determines the plant's height and overall structure.

Booting stage: The growing point transitions from within the stem to just above the soil surface, enclosed by the flag leaf sheath. This stage marks the beginning of head emergence.

Heading and flowering stage: The reproductive phase is marked by the emergence of the wheat head, which contains florets. Pollen is released from the anthers and travels to the stigma, leading to fertilization. Pollination occurs when pollen from the anthers fertilizes the stigma of the floret, leading to grain development. Hence, this stage is crucial for grain development. The wheat head then starts to emerge from the flag leaf sheath—florets containing the reproductive structures form within the spikelets.

Leaf morphology: The shape of the wheat flag leaf can augment light absorption, hence enhancing photosynthesis and grain yield [81]. Leaf attributes, including flag leaf angle (FLAN), flag leaf width (FLW), flag leaf length (FLL), flag leaf length-to-width ratio (FLR), and flag leaf area (FLA), might enhance wheat grain production. FLL, FLW, and FLA are significant agronomic traits [81, 82]. Furthermore, [82] revealed that these growth features had a substantial positive correlation with the number of kernels per ear and kernel weight per ear [83, 81, 82, 84], indicating that leaf traits affect yield-related variables. Therefore, studying the agronomic characteristics of leaf morphology could have great potential for breeders, researchers, and producers.

Plant height: The introduction of new wheat genotypes bred with reduced plant height has not only led to increased genetic gains in spring wheat but also played a substantial role in the global surge in wheat productivity [85, 86, 66]. Genes such as *Rht-B1b, Rht-B1c, Rht-B1d, Rht-B1e, Rht-B1f, Rht-B1 g, Rht-D1b, Rht-D1c, Rht-D1d, Rht4, Rht5, Rht7, Rht8, Rht9, Rht12, Rht13, Rht14, Rht16, Rht18,* and *Rht21* are essential for modifiable plant height in wheat genotypes, thereby reducing coleoptile and internode length and overall plant height [87]. This, in turn, boosts grain yield [88] by enhancing assimilation partitioning to the ear, painting a promising picture for future wheat production. Thus, it is necessary to employ various cultivation technologies to unlock its potential.

Length of spike: Understanding spike length is crucial for farmers to make informed choices on wheat variety selection, agronomic management, and yield enhancement. Observing spike development and appropriately modifying cultivation methods can lead to increased output, improved grain quality, and greater resistance to environmental challenges [89]. The length of the spike (ear) in wheat refers to the distance from the base to the tip of the wheat head, where the grains are developed. This key morphological trait significantly influences yield potential, as it determines the number of spikelets per spike and indirectly affects grain number and weight [90].

1.5.2. Reproductive and yield traits

Reproductive trait stages begin when the flag leaf is visible, the ligule of the flag leaf is visible, booting and flowering, panicles (heads) emerge from the top of the plant's stems, continue flowering, and end with the ripening of the kernels [91, 79].

Grain filling: After successful fertilization, the kernels develop and fill with nutrients and carbohydrates. This period is vital for determining grain yield.

Grain ripening and maturity: The floret's ovary develops into a wheat kernel after successful fertilization. The kernels mature and harden, signaling the end of the growth cycle. During this phase, the plant's resources are channeled into grain filling [92].

Kernel weight: An increase in the mass of one thousand wheat grains has been strongly linked with boosting grain yield [93, 94]. For newly bred wheat genotypes, the improvement in one thousand grain yield has been reported to range from 39 to 55 g, while for check cultivars, it has been reported to range from 29 to 49 g [65, 66]. Reports by [95, 96] indicated that wheat kernel weight varies from 33 to 55 g in prehistoric cultivars and from 41 to 57 g in contemporary wheat cultivars in the USA. Thus, evaluating various cultivation technologies to determine which can bridge the history of a thousand-weight grain record within Russia is worth noting. This highlights the importance of assessing multiple cultivation technologies to determine which technology could bridge the thousand-weight grain gap within Russia's wheat production systems.

Number of grains per spike: The number of grains per spike is a crucial indicator affecting wheat grain yield. Various studies have investigated the relationship between the number of seeds per spike and yield, revealing that increasing the number of grains per spike can improve grain yield [66, 96, 97].

Protein content: Optimizing protein content is essential for ensuring nutritional quality and suitability for various end-use products.

Gluten strength: Wheat with superior gluten strength is preferred for bread-making because it retains gas during fermentation

Milling and baking properties: The hardness of grains, milling quality, and baking characteristics determine wheat's suitability for flour production and bakery products [98].

1.6. Agronomic technologies utilized in spring wheat cultivation

1.6.1. Requirement of soil conditions and predecessor crops

Spring wheat survives after perennial and annual leguminous grass; however, planting spring wheat should be avoided after sunflowers due to the heavy carrion it leaves. Planting spring wheat after winter wheat is also not recommended, as it can accrue pathogenic infections and pests, underscoring the importance of selecting the proper predecessor for a healthy and high-yielding crop. The production of any wheat crop requires specific soil conditions and is affected by the prior crops cultivated in its fields. The ideal preceding crops for wheat include perennial and annual grasses, green manure, corn, legumes, buckwheat, and rapeseed. These crops augment soil nitrogen concentrations, regulate weed proliferation, raise the accessibility of vital nutrients, and diminish the risk of moisture-induced diseases. It is advisable to avoid sowing wheat right after barley, given that both crops are prone to root rot. In a similar vein, sorghum and sunflower are not ideal as they deplete the soil moisture to a critical level and are harvested at a late stage [99].

Field preparation for wheat sowing commences immediately following the harvest of the preceding crops. Pre-sowing treatments involve aerating the field, controlling weeds, preserving moisture, and leveling the soil to ensure optimal conditions for seeding. Harrowing and cultivation are established techniques for soil preparation [99].

1.6.2. Seed preparation for sowing

Before sowing, the seeds are carefully cleaned of all impurities and sorted by size using a seed sorter. All damaged seeds are discarded. Seeds are checked for germination percentage before pre-sowing treatment. In recent years, most wheat farmers have begun to powder spring wheat seeds with powdered superphosphate (1-1.5 kg seeds) on or before the day of sowing. This method has been reported to increase seed germination by 6-15% (depending on soil moisture and temperature) and increase wheat yield from 1.5-2.9 t ha^{-1}

[100]. Seeds from high-yielding plots are chosen for sowing because of their exceptional physical and biological characteristics. Before planting, the most robust and viable seeds receive seed treatments: they are subjected to pesticide applications and authorized agrochemicals in Russia [101]. A crucial process, including encrusting, entails applying a hydrophobic polymer to seeds and incorporating fungicides, fertilizers, and growth stimulants. This treatment protects the seeds from infections in the soil and on the seeds themselves, thereby improving plant survival during the winter or spring seasons. Encrusting protects seeds against mold, mechanical damage, and various environmental stressors while enhancing overall germination rates [102].

1.6.3. Timing and methods of fertilization

Spring wheat demands soil fertility and responds well to complete fertilization, especially nitrogen, potassium, and nitrogen-phosphorus fertilizers. Spring wheat consumes about 4 kg of nitrogen, 1 kg of P_2O_5, and 2.5 kg of K_2O per 1 kg of grain with the appropriate amount of straw [103]. According to [104], to obtain a yield of a solid or hard grain of 30-35 t ha^{-1}, the fertilizer rate should be approximately N45-60, P40-60, and K20-40. Fertilizer rates should be differentiated depending on the zone, predecessor, soil fertility, and other factors. Nitrogen fertilizers can be used in autumn to add ammonia water, anhydrous ammonia, and other ammonia forms. Simple granulated superphosphate - P10-20 - is everywhere added to the rows during sowing. Quickly soluble nitrogen and potassium fertilizers are not applied everywhere, so the soil solution concentration does not increase in the area where the seeds are located. Otherwise, germination may be delayed. The rate of fertilizers applied is considered in the autumn or early spring when soil analysis is completed within the soil layers of 0-40 cm. Also, it should be noted that applying higher doses of nitrogen before sowing can harm spring wheat by causing massive vegetative growth, depleting soil moisture reserves, increasing the crop's susceptibility to diseases, intensifying lodging, and reducing grain yield from the crop biomass. Thus, farmers should understand the risks of over-nutrition and the importance of balanced fertilization for high-quality grain production [104; 105]. Spring and winter wheat varieties are widely grown across Russia, with their primary difference being in the vegetation period. Winter wheat has a vegetation period of around 280 days, whereas spring wheat can be harvested approximately 100 days after planting, making its growing season three times shorter than winter wheat. Spring wheat is sown in spring and harvested at the end of the warm season, while winter wheat is planted in autumn, with seedlings surviving under snow during winter. Although spring wheat typically yields less than winter wheat, cultivating it is easier in the fields. Crop rotation is usually observed using these sequences: peas- spring wheat- spring rapeseed-spring barley, or peas-winter wheat-spring, rapeseed-spring wheat-spring barley.

1.6.4. Tillage practices

Soil cultivation for spring wheat depends on the zone, cropping history or predecessor, weediness, slope, and other field and soil features. Carrying out the autumn tillage system immediately or soon after harvesting the predecessor is essential. This increases moisture reserves in the soil and reduces the number of weeds and pests. After harvesting perennial grasses, disc peeling is carried out (sometimes after 10-15 days – or cutting of grown grass with a flat cutter to a depth of 12-14 cm), and then after 2-3 weeks - plowing with a plow with cultivated dumps and skimmers for 20-22 cm, embedding the layer at the bottom of the furrow so that the grass could not grow and litter the crops [106]. After leguminous crops, stubble crops, and other early harvested predecessors' debris are incorporated into the soil (with two stubbles - disc and then plowshare cultivators as perennial weeds grow) or semi-fallow cultivation of autumn (early plowing at 20-22 cm with harrowing and one or two autumn cultivations to control weeds). After corn and sunflower, tillage includes cross-disking and plowing with skimmers to a depth of 20-22 cm. Most times, all fieldwork in the spring is carried out with caterpillar tractors T-150, DT-75, etc., which do not compact the soil as much as the wheels of tractors K-701 and T-150K [100, 107].

1.6.5. Seeding

Before planting, large healthy wheat seeds are sorted to ensure that they are free from infections. Their 1000-grain weight must range from 35-40 g for soft wheat and at least 40 g for durum wheat. These weights must be obtained from high-yielding certified companies before they can be used for sowing. These seeds are disinfected by encrusting in the same way as winter wheat seeds, preventing the development of smut, root rot, and seed mold [108]. Spring wheat varieties are cultivated during the early sowing period, which ensures the friendly emergence of seedlings and better rooting of plants. Early crops are less affected by drought, damage from cereal flies, flea beetles, and other pests, and rust. In the Central Black Sea Region, spring wheat is usually sown when the soil reaches a temperature of 5-6°C in a narrow-row method with an SZU-3.6 seeder. The sowing depth of spring wheat is usually 4-5 cm. If necessary, it can be increased to 7-8 cm, but this may delay the emergence of seedlings, so seeds should be planted in moist soil. In the Central Region, durum wheat is usually sown from 2.0-2.5- 5 million and soft wheat - 4-5 million germinating seeds ha^{-1}. It is also possible to use significantly lower seeding rates (1.5-2.0 million $pieces^{-1}$), depending on the agroecology, which provides the optimal density of productive stems for harvesting (450-550 pcs^{-1}). Spring is characterized by high-quality yields, producing high-quality grains [8, 106].

1.6.6. Crop Management

Weeds, diseases, and pests cause significant damage to wheat production worldwide, including the non-Chernozem zones in Russia. Thus, all agronomic measures and techniques that contribute to suppressing pest and disease incidence are crucial. A well-developed plant can resist pest and disease damage. Effective crop management can be accomplished through the following practices: harrowing, crop rotation, superior tillage techniques, timely sowing with high-quality seeds, adherence to the spring wheat rotation sequence, appropriate and timely fertilizer application, irrigation, utilization of plant protection products, prompt harvesting, and proper seed storage [109]. Sowing good-quality seeds and balanced agrochemical management reduces the incidence of diseases and pests. Observing the appropriate harvesting time helps to preserve the crop from post-harvest losses, pests, and diseases. Also, delays in threshing, especially in the rains, could lead to severe grain infection with *Helminthosporium* leaf blight (HLB) and other diseases. Hence, crop care during all plant growth stages is essential, and the use of resistant varieties, along with crop protection chemicals for disease and pest control, is indispensable to increase wheat yields [110, 111].

1.6.7. Harvesting spring wheat

At present, two harvesting techniques are employed: the separate collection method and the single-phase harvesting approach. Both methods consider all combinatorial aspects, including ripening time, moisture content, equipment availability, weather conditions throughout the harvesting period, plant height, density, field weed conditions, and stem stands. These agronomic characteristics facilitate the efficient harvesting of wheat while minimizing the degradation of grain quality. Typically, most regions involved in wheat cultivation employ both techniques [112]. Generalized data indicate that the filling and development of wheat grains conclude during the intermediate phases of waxy ripeness, when the moisture content of the seeds attains around 25-30%. The utilization of a combine harvester and the selection of rolls for threshing occur when the grain moisture content attains a range of 12-20% [112, 113]. Today, combine harvesters are used to harvest large wheat fields. This agricultural machine concurrently gathers, threshes, and winnows grains. The combine harvesters cut the crop residue into tiny bits, which are then broadcast across the field by the rear discharge. Harvesting at a slightly higher moisture content of 18% is also essential if quality losses are considered. To prevent significant declines in grain quality, wheat can also be harvested as soon as it has dried to around 12.5% grain moisture content. These grains can further be dried to a moisture content of less than 12% after harvest to prevent the risk of fungi and mycotoxins developing during storage [114]. The optimal harvesting period, when the highest biological yield is maintained, is only 7-10 days in stable weather [115]. When harvesting is delayed, the gap between biological and actual yields increases. The magnitude of crop losses will depend on many factors, but above all, the weather conditions are critical for more observation before the operation can be carried out. When the wheat is overdue, yield losses occur due to the shedding of the grain and the breaking off the ears, leading to a decreased grain yield. Usually, the optimal height of the stems should be combined with a good density of the stem, at least 250-300 productive stems m^{-2}, and at a cutting height of at least 18-22 cm [115, 114].

1.7. Disease incidence and severity

Assessment of plant diseases, or Phytopathometry, involves measuring and quantifying plant diseases and is, therefore, fundamentally critical in studying and analyzing plant disease epidemics. Disease incidence is a general term used to denote the amount of disease, commonly expressed as either disease intensity (proportion of the total number of plants that are infected) or disease severity (proportion of total plant area that is infected [116, 117].

1.7.1. Mitigating strategies for incidence and severity of diseases of spring wheat cultivars

A disease is any adverse variation from a plant or an organism's normal structural or functional condition, typically accompanied by signs and symptoms. It is distinct from physical injury in origin. A diseased plant or organism frequently displays symptoms or indicators that point to its abnormal condition. Since wheat is the most widely cultivated cereal crop in the world, it is estimated to be cultivated on 237 million ha of land annually, with an estimated yield of 420 million tons. It contributes at least one-fifth of our daily caloric intake [118, 119, 120]. Thus, disease management is crucial for wheat production. However, ecological factors, hereditary prevalence, biotic factors (such as pests and diseases), and abiotic factors have impacted wheat output. Pathogens (fungi, viruses, and bacteria) are amid the biotic stressors that may be key indicators for the average global losses of 21.5% of wheat yield [121]. The analysis of several reports indicates that wheat is susceptible to various diseases, including parasitic infestations and bacteria, viral, and fungal infections [120, 118, 121]. Among these diseases, Fusarium spp., powdery mildew, rust, Septoria spp., and tan spot, amongst others, are raising research focus.

1.8 Fusarium head blight of spring wheat

Fusarium head blight (FHB), sometimes referred to as scab, is a fungal disease that causes severe damage to cereal grains such as wheat, barley, oats, rye, corn, triticale, canary seed, and many forage grasses. FHB is a significant and destructive fungal disease impacting wheat. It is associated with numerous species of fungi of the genus Fusarium [122]. FHB predominantly impacts wheat during the blooming phase, resulting in symptoms including spikelet bleaching, shriveled kernels, and pink or orange fungal proliferation on affected heads. FHB markedly diminishes wheat production, leading to decreased yield, grade, and end-use quality. Compromised grains may be diminutive, shriveled, and inferior in volume and quality, which is associated with diminished selling prospects. Contaminated grains may include mycotoxins that negatively impact human and animal nutrition [123]. Fusarium species mainly make trichothecenes, zearalenone, fumonisins, and the newly found mycotoxins beauvericin, enniatins, fusaproliferin, moniliformin, and deoxynivalenol (DON), which are dangerous to health when they are in food and feed [124]. Based on its relevance to science and industry, the prevalent species, *F. graminearum* (teleomorph *Gibberella zeae*), is currently placed fourth among plant fungal diseases [125, 126]. Some significant components of the infectious process have been clarified, but the biology of *F. graminearum* infection is still not entirely understood. Additionally, it has been investigated how signal transduction pathways that support invasive growth, sexual reproduction, and adaptive stress responses affect FHB symptoms [127].

1.8.1 Disease cycle, epidemiology, and its economic impacts

According to [128], 19 different Fusarium species can cause wheat FHB. However, the most significant are *F. culmorum, F. avenaceum (teleomorph G. avenacea),* and particularly *F. graminearum (*teleomorp*h G. zeae)*. In the soil of debris of wheat and other cereal plants, *Fusarium* species thrive and overwinter. According to [129], the saprophytic mycelium on stubble residues such as chlamydospores (*F. culmorum*), perithecia (*F. graminearum*), and macroconidia creates the inoculum for the infection in the following growing season. Spores are dispersed by wind, rain, and insects. Warm, humid weather before, during, and after flowering favors disease inoculum generation and infection of growing grains [130].

The biology of different Fusarium species varies, for example, in the spores they generate, and their distribution within agroecosystems will depend on these traits. Fusarium species form asexual conidia, while particular species, including *F. graminearum* and *F. avenaceum*, also produce ascospores sexually [131]. In the genus *Gibberella*, the sexual stages were previously identified by their teleomorph names [132]. Some species, such as F. culmorum and F. graminearum, also produce chlamydospores with thicker cell walls that may be able to live in the soil [133, 134]. These fungi then spread their spores to invade new plant sections. Conidia, the asexual spores, depend on wind or rain for liberation, whereas sexual ascospores are known to be released by active mechanisms of the perithecia [135].

According to research by [136], ascospores can travel farther by wind than macroconidia, which are said to be splash-dispersed over short lengths inside the canopy. The type of spore may also play a role in the development of the disease. For example, it has been demonstrated that *F. graminearum* ascospores are less successful than conidia at causing FHB, even though the difference in FHB severity between the two spore types is minimal [137]. To allow the pathogen to survive saprotrophically, contaminated agricultural residues are a crucial source of Fusarium inoculum. According to [138], maize is the preceding crop associated with the highest risk of FHB because it is an excellent host for *Fusarium* spp. and produces significant residues.

Fusarium Head Blight (FHB) is a monocyclic disease, with the pathogen present in sexual structures called perithecia, ascospores, as well as in asexual spores known as macroconidia or microconidia in organisms that possess only an anamorph stage. The main inoculum of the disease is believed to be these spores. Additionally, both gramineous and non-gramineous weeds may serve as alternative hosts and sources of inoculum, as well as a host range for Fusarium [123, 140]. During optimal meteorological conditions for wheat anthesis, the plant becomes susceptible to infection when inoculum is dispersed by rain or wind, settling on exposed spikelets. The spores proliferate on the spikelet tissue and form germination tubes.[141, 142, 143, 144, 145, 146].

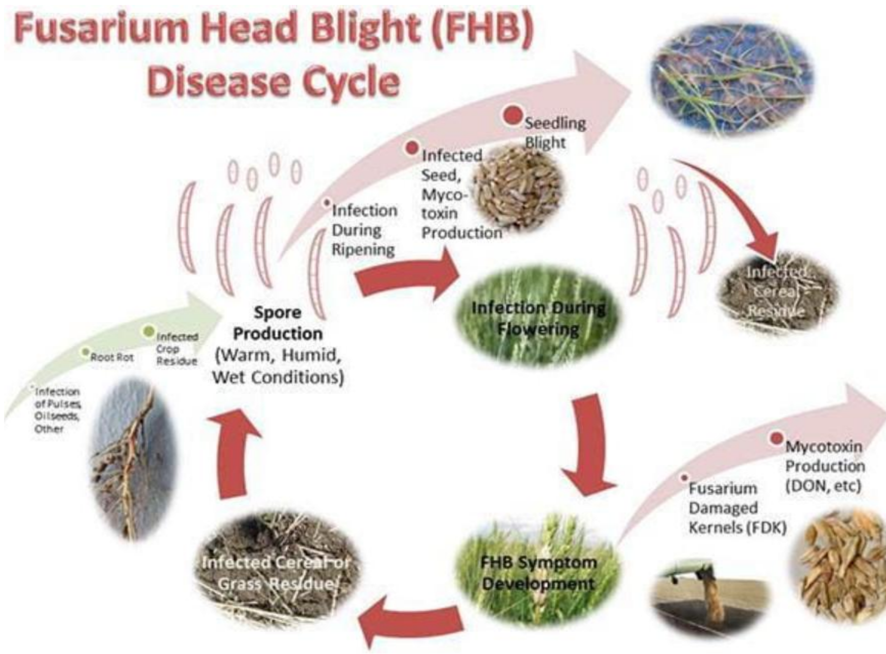


Figure 3. Fusarium head blight disease cycle [139].

1.8.2 Pathogen life cycle and infection process

A monocyclic disease is Fusarium head blight, and the pathogen can also be found in sexual structures called perithecia ascospores or in asexual spores known as macroconidia or microconidia in the case of organisms that only have an anamorph stage. The major inoculum of the disease is thought to be these spores. Furthermore, gramineous and non-gramineous weeds can act as an alternative host and source of inoculum and a host range for Fusarium [123, 140]. When the weather is right during wheat anthesis, the plant is vulnerable to infection, the inoculum is splattered by rain or blown by the wind and lands on open spikelets. The spores germinate on the spikelet tissue and create germination tubes [141, 142, 143, 144, 145, 146].

1.8.3 Fusarium species and mycotoxin production

Alternaria, Aspergillus, Claviceps, Fusarium, and Penicillium are all types of mold fungi that make mycotoxins, which are secondary metabolites. Fusarium species, such as FHB, make a lot of mycotoxins, mostly trichothecenes, zearalenone, fusaric acid, fumonisins, and new toxins such enniatins, beauvericin, moniliformin, and fusaproliferin. Due to the toxic effects of these metabolites on human and animal health, it is essential to detect and quantify these toxins in food and feed. However, this process is challenging because it is expensive, time-consuming, and laborious [147, 146]. An enormous cluster of highly biologically diverse animal and plant pathogenic species belongs to the genus Fusarium [132]. These species influence many agronomic crops and are also used as biocontrol agents, valuable industrial enzymes, disease-causing agents, and are probably the most common fungi that produce toxins. [148]. *Aspergillus*, *Penicillium,* and Fusarium are filamentous fungi that create mycotoxins. These secondary metabolites can be poisonous or cancer-causing when formed in the proper environmental conditions [149].

Fusarium produces four emerging mycotoxins, including fusaproliferin, beauvericin, enniatins, and moniliformin, in addition to three of the most significant mycotoxins, such as fumonisins, *trichothecenes*, or zearalenone [150]. Among all, Deoxynivalenol (DON) and zearalenone (ZEA) are the most common and harmful toxins produced by Fusarium infections, found in agricultural products [151]. Mycotoxin belongs to the Trichothecene family and is deoxynivalenol. Despite being one of the least damaging trichothecenes, this toxin is frequently found worldwide. According to [152], its occurrence is thought to indicate the potential existence of other, more toxic trichothecenes. Also, consuming this contaminated feed by cattle has been linked to several detrimental health impacts, such as feed rejection, decreased weight gain, diarrhea, and emesis [153]. EU laws on cereal safety set the following limits for DON in cereals and cereal-based products: unprocessed grains other than durum wheat, oats, and maize (1250 g kg^{-1}); unprocessed durum wheat and oats (1750 g kg^{-1}); unprocessed maize (1750 g kg^{-1}); and cereal flour, maize grits, and maize

[154]. In several nations, the maximum acceptable amount of DON has only been defined for feed and complete feeding stuff for pigs, which is 500 g kg^{-1} [155]. The biological actions of mycotoxins pose a risk to human and animal health. Consuming these substances can lower infection resistance and result in chronic disease, morbidity, and mortality [156]. Most mycotoxins are heat and chemical-resistant and remain stable during food preparation. Animal products can also expose humans to mycotoxins [157, 158].

1.8.4 Current disease management strategies

Biological Control: To prevent FHB from spreading on wheat, microorganisms harmful to Fusarium species or biological secondary metabolites are utilized. To stop perithecia from forming, these bacteria can be sprayed directly on wheat spikes or on crops that remain from the last season. For example, fungi from Trichoderma spp., Clonostachys rosea, Aureobasidium pullulans, and Bacillus spp., as well as bacteria from Lysobacter enzymogenes, Pseudomonas spp., Lysobacter spp., and Streptomyces spp., were effective against Fusarium [159]. In the field, the fungus Clonostachys rosea was used to eliminate wheat leftovers infected with several Fusarium species. Fungal DNA showed that Fusarium growth dropped by 68 to 98% after 90 days of treatment and was no longer detectable after 180 days [160]. Three new fungus species with a high protection ratio of 75% to 100% on detached wheat spikelets were described by [161] as Aureobasidium proteae, Phim aglomerate, and Sarocladium kiliense. Researchers found the basidiomycetous yeast Cryptococcus nodaensis OH 182.9 in wheat anthers [162].

Cultural Practices: FHB was stopped by spreading the anthesis periods through alternating planting dates, using types with different maturities, and using moderately resistant cultivars [163, 164]. Also, decreasing the amount of inoculum during wheat anthesis can significantly aid disease management. You can do this by tilling the ground and burying the crop residues, especially if the last crop was one of the key hosts for Fusarium species, like maize or barley. This method stops perithecia from forming and ascospores from being released while wheat spikes are growing [165, 140]. Another way to minimize inoculum pressure is to not plant FHB cultural hosts, like maize, in wheat fields before planting [166, 167].

Chemical control: Although the actual reductions are highly variable, chemical treatment using the commonly used demethylation inhibitor (DMI) class fungicides such as tebuconazole (Folicur), prothioconazole plus tebuconazole (Prosaro), and metconazole (Caramba) results in no more than 60% control of FHB and 30% to 50% control of DON in wheat [123, 168]. Additionally, several pesticide restrictions, such as inadequate coverage and improper application, have been noted, posing significant challenges for farmers [123]. It has been demonstrated that newer fungicides are more effective against *Fusarium* spp. than DMI class fungicides, such as phenamacril, a cyanoacrylate molecule that claims its antifungal effect on susceptible *Fusarium* by blocking the activity of crucial actin-motor protein [169].

1.8.5 Host plant resistance to Fusarium head blight

Host resistance has long been considered the most practical and effective means of FHB disease control, but breeding has been hindered by a lack of effective resistance genes and by the complexity of the resistance in identified sources. No source of complete resistance is known, and current sources provide only partial resistance. Morphological and phonological characteristics represent passive resistance to FHB, whereas physiological characteristics in wheat represent active resistance. Passive resistance is influenced by morphological and phenological characteristics such as plant height, wheat awns, small and short floral openings, and the period of retained anthers [169]. The spring wheat cultivar Sumai 3, including derived lines such as ‘Ning 7840’, is arguably the most widely used source of resistance to FHB in the world and is undoubtedly the best characterized. It has been used in Chinese breeding programs for at least 20 years, and since its introduction into the USA, it has been used extensively by both spring wheat and winter wheat breeding programs [170]. Plant height allows wheat spikes to withstand being dislodged by raindrops that transport crop residues and inoculum from the soil surface. Awns in wheat capture the inoculum and enhance natural infection, while their absence diminishes it. Retained anthers and pollen can capture the inoculum, aiding in spore germination and fungal invasion; however, a constricted floral aperture reduces the floret's exposure to the inoculum, hence enhancing resistance [171, 170].

1.8.6 Strategies for mitigating FHB incidence

Effective management of FHB requires a combination of preventive measures, cultural practices, and timely interventions as discussed below.

Crop rotation: Implementing diverse crop rotations breaks the disease cycle, reducing the buildup of fusarium spores in the soil. Avoiding consecutive wheat plantings can help minimize FHB incidence [172].

Resistant varieties: Planting wheat varieties with inherent resistance or tolerance to FHB can significantly reduce disease severity [173, 171]. Breeding programs should develop more cultivars with improved resistance to specific Fusarium species.

Fungicide application: Timely fungicide applications during wheat flowering can help suppress FHB development. Fungicides specifically targeting Fusarium species can effectively follow disease forecasts [174].

Optimal plant density: Planting at recommended plant densities allows for better air circulation, reduces humidity around the wheat heads, and inhibits fungal growth [173].

Nutrient management: Appropriate mineral nutrient management, particularly nitrogenous nutrients, can decrease extreme vegetative growth, which also favors FHB development. Surplus nitrogen applied to wheat crops can lead to an excess canopy formation, creating a humid microenvironment [112].

Delayed planting: Planting slightly later in the season may reduce the period of flowering overlap with Fusarium spore production, potentially lowering disease incidence [173].

Deep plowing: Incorporating infected crop residues through deep plowing helps reduce the inoculum source for the next growing season [173].

Biological control: Applying beneficial microbes and antagonistic organisms can suppress Fusarium growth and limit disease development [159].

Host resistance stimulation: Applying elicitors or bio-stimulants can trigger the plant's natural defense mechanisms, enhancing its resistance to FHB.

Integrated management approach: The most effective means of mitigating FHB incidence is to combine several strategies in an integrated disease management plan. A holistic approach considers regional climate, cultivar characteristics, disease history, and local practices [175].

Research and monitoring: Continuous research and tracking of FHB epidemiology, pathogen populations, and resistance mechanisms are vital for developing and adapting effective mitigation strategies [176]. Mitigating FBH incidence requires a multi-faceted approach incorporating diverse strategies and cultivation technologies. The goal is to minimize the negative impact of FHB on wheat yield, quality, and food safety. By integrating preventive measures, resistant cultivars, and timely interventions, farmers can effectively manage FHB and contribute to sustainable wheat production and global food security.

1.9 Septoria leaf blotch (SLB) of spring wheat

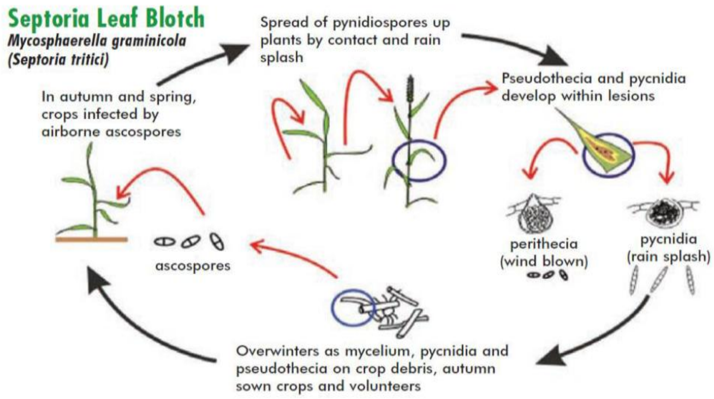
SLB is the most significant foliar wheat disease in most wheat fields. It is caused by *Z. tritici*, previously known as *M. graminicola*, and its previous name for the asexual stage is *S. tritici*. The disease is spread by wind-distributed ascospores, which are continuously released from crop detritus in the autumn to early winter and again in the late spring to early summer. In most regions where spring wheat is grown, SLB and ears have long been one of the most prevalent and harmful diseases [177]. When Septoria leaf blotch affects wheat, the leaves prematurely dry out, and grain is only spilled at the cost of the green stem and spike components. When the leaves are affected, a hollow is created in the grain, which has a mass of 1000 grains, with a small grain unit at the end. It can decrease spring wheat productivity by 25-60%, affecting seeds' germination and energy capacity, which can diminish by 7-12% [178, 179, 180].

The SLB *S* is a foliar fungal disease affecting wheat-growing regions in Europe, South America, North Africa, and Central Asia. This is because the wheat growing season aligns with meteorological conditions favorable for the disease's proliferation, characterized by high humidity and temperatures ranging from 15 to 20 °C [181]. SLB is prevalent in the Mediterranean basin, the elevated plateaus of Ethiopia and Tanzania, South America, Australia, and Western Europe, attributed to moderate climates and a rainy season coinciding with wheat cultivation in these regions. High relative humidity and mild temperatures (20–25°C) facilitate the development of this disease. Even in harsh climatic conditions, susceptible types could contract the disease [182].

1.9.1 Disease cycle and epidemiology and its economic impact

The fungi Septoria leaf blotch (SLB) disease survives in stubble from one season to the next, allowing its spores to be released from the stubble after rain or heavy dew. The spores are then spread by wind and rain splashes [183]. In Siberia, SLB is a fungus species found in spring wheat and predominates over due to its faster (8–10 times) *pycniospore* germination and host plant tissue colonization [183]. Additionally, Siberian Spring wheat has been found to include *Phaeosphaeria avenaria* f.sp. *triticae* Shoem. and C.E. Babc. (syn. *S. avenae* f.sp. *triticea*) [180]. The same species can also severely affect winter wheat harvests [184].

Each plant pathogen's epidemiological characteristics and environmental requirements ensure that the disease is more ecologically plastic and difficult to control. On the same plant, both species may coexist. *S. tritici* mainly affects the leaves, intensifying more on young tissues than on older ones. *P. nodorum* may thrive and grow on dead tissues, and it can harm both leaves and ears equally [184]. In many regions of the world, Septoria leaf blotch is currently one of the most significant diseases of bread wheat and durum wheat (*Triticum turgidum* L. sub sp. durum) [185,186]. Wheat yield losses due to SLB can range from 30% to more than 70% (Figure 4). In Ethiopia, it can result in a yield loss of up to 82% in all bread wheat varieties introduced [187].



Disease-cycle of septoria leaf blotch, reproduced with permission of the AHDB, from the Encyclopaedia of Cereal Diseases.

Figure 4. Septoria leaf blotch disease cycle. Source: [188].

1.9.2. Pathogen life cycle and infection process

If the plant is drip-wetted at the ideal temperature for at least eight hours and the relative humidity is between 98% and 100%, SLB plant infection is very successful. As a result, SLB most frequently appears in places with enough moisture. In some circumstances, *Septoria* blotch can be harmful in arid environments. This is so because the pathogen takes advantage of a periodic wet period brought on by frequent dewfall [180]. Depending on the hydrothermal conditions, Septoria leaf blotch can incubate between 6 to 49 days. Regression research revealed that 45% of the pathogen's latent period fluctuation is caused by temperature, 12% by its population density, and just 3% by the amount of hydration. This shows that the pathogen is practically moisture-independent once in the ecological niche. Nevertheless, the presence of droplet-liquid moisture is crucial for the life cycle of the organism in the external environment during all stages of the transmission mechanism (separation from the source of the causative agent, transmission of propagules with airborne droplets, and germination and incorporation into the tissues of susceptible plants [187, 183,178, 189].

1.9.3. Current disease management strategies

Biological control: For the control of SLB disease, biological control strategies offer a more enduring application of bioagents. A prolonged latent period and gradual disease development also favor biological control because they give a microorganism enough time to disrupt SLB [187, 189]. Several biological controls are being tested for SLB right now, and while some have shown promise, none are yet accessible for commercial production. In the world today, *Trichoderma* spp. fungi have been employed as bioprotectant agents to protect against leaf spot diseases in wheat plants. *T. harzianum* is another bioprotectant that causes a biochemically triggered response in wheat plants, acting as an efficient antagonist against SLB [190, 191].

Chemical control: In locations where SLB is known to occur, seed-applied fungicides can be used to prevent early infection. If required, efficient foliar fungal treatments are available. Before applying a fungicide, it is crucial to appropriately identify Septoria leaf blotch, as it might be mistaken for other nutritional conditions such as zinc insufficiency or aluminum toxicity [189].

Cultural control: It is sometimes called traditional cultural practices, which can reduce the prevalence and severity of SLB. Implementing crop rotation with non-hosts and maintaining cleanliness through the thorough removal of agricultural debris from the field can diminish the inoculum levels available to initiate a new disease cycle. Due to the ascospores' long-distance dissemination, it may be less effective in the wild, but it might be helpful if coordinated within a region. To prevent ascospore flights in a freshly planted wheat crop, late winter wheat planting (e.g., mid-October versus late September) may also be employed to reduce the severity of the initial infection [192].

1.9.4. Host Plant Resistance

According to research, the easiest and cheapest way to deal with SLB is to plant resistant varieties. Host resistance is the most cost-effective and safest method for managing diseases, and understanding resistance loci is crucial for effective resistance breeding programs. Winter wheat is more often resistant to M. *graminicola* than spring wheat, and this resistance might be either qualitative or quantitative. Different types of plants react quite differently to Z. tritici infection. Plant resistance to various diseases varies in regions with a history of significant disease pressure. Although all cultivars are susceptible to infection, planting types with high resistance levels will reduce output losses. Whenever possible, choose cultivars with intermediate resistance to both stages of this disease [192, 193, 194].

1.9.5. Integrated septoria leaf blotch management

A more realistic and strategic approach to disease management combines cultural, physical, chemical, host resistance, and other strategies to keep the disease at an economically acceptable threshold [195]. Some integrated techniques that could lessen the impact of the disease include adopting well-drained crop-rotation practices, using treated or healthy seeds followed by foliar sprays using fungicides, and collecting and burning infected waste after harvest [196].

1.10. Powdery mildew disease of spring wheat

Powdery mildew is a significant concern for crops like wheat, barley, and grapes, causing substantial yield and quality losses. In grain, powdery mildew (*B. graminis*) can lead to yield losses of 10-50% [121]. Different wheat-producing regions worldwide may have powdery mildew infection all year round. Both qualitative (grain end-use quality) and quantitative (final grain yield) losses result from powdery mildew infection in wheat [197]. Crops with powdery mildew have lower chlorophyll content and photosynthetic activity [198]. It has been discovered that when a severe disease infection occurs, crop production losses can reach 60%, and it usually results in a yield drop of 5-40% [199]. Mains presented the earliest documentation of powdery mildew in 1933, and the importance of powdery mildew was not appreciated until the early nineteenth century, before the adoption of rising fertilizer application rates [200].

B. graminis f. sp. *tritici* (Bgt) is an obligate biotrophic fungus, which can result in yield losses to crops, and in severe situations, even up to 50%-60% [201, 202, 203]. According to worldwide genome-wide association studies, wheat powdery mildew started in the Fertile Crescent and then spread across Eurasia and later to other continents due to active human migration and trade [204].

1.10.1 Powdery mildew disease cycle, epidemiology, and its economic impacts

Powdery mildew can be found on any plant component; however, distinctive indications of powdery mildew include a buildup of whitish powdery mycelia on the entire leaf area and stems, which subsequently limit the leaf area for photosynthesis. Black-colored *cleistothecia* bodies can intertwine within the whitish mycelia as the disease spreads through plants. Infected crops produce shriveled grain; early infection can decrease emergence [205]. Powdery mildew pathogens produce two types of pathogenic spores: conidia and ascospores. These spores germinate in humid environments and, afterward, demand 10-22°C combined with a less humid environment for appropriate disease development [206, 207]. The pathogen's rapid spread and adoption are facilitated by its brief life cycle, the ease with which airborne spores can travel great distances, and the potential for sexual recombination that could create new virulent races [208]. According to studies, fungus decreases photosynthesis on leaves, lowers the leaf assimilation index, and adversely affects grain yield components [209]. When it occurs early, infection during the tillering, stem elongation, and booting phases significantly impacts production, leading to a decreased kernel weight and, ultimately, a lower yield [199]. When infection occurs before or during blooming, and the flag leaf becomes infected, losses in grain production related to wheat powdery mildew infection can exceed 40% [197]. According to [205] research, the disease can result in crop losses of up to 62%. With climatic change and other incorrect cultural applications, powdery mildew frequency and severity have recently increased more noticeably [210].

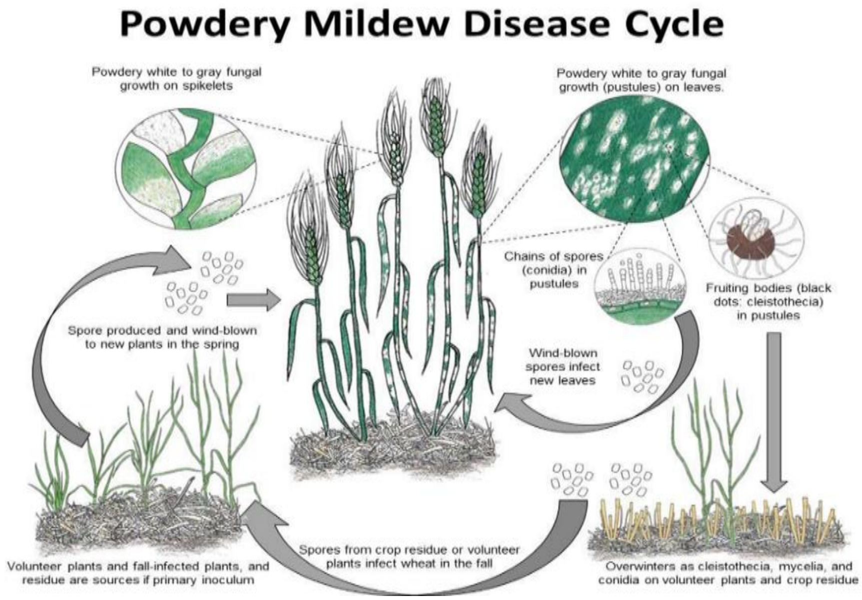


Figure 5. Powdery mildew disease cycle [211].

1.10.2 Pathogen life cycle and infection process

The classification of *Blumeria* species depends on the host each one affects. Mutation and genetic recombination result in the fungus' pathotypic evolution and the formation of new races [212, 213]. Infection with powdery mildew causes significant transcriptional reprogramming that is tightly controlled by several pathways [214, 215, 216]. Mycelium, or cleistothecium, is the first stage of the infection process. The cleistothecium, which is black, is formed during sexual phases. The conidia transmit disease during various growth stages. The entire crop may suffer if the disease attacks the plant while it is still in the seedling stage. The disease is most frequently seen on leaves and stems, and its symptoms include the emergence of white cottony mycelia and an abundance of spores [205]. Host phenology, susceptibility, and disease-conductive environmental variables are infection factors [217]. Although infections can occur in temperatures as low as 5 °C and as high as 30 °C, humid conditions with temperatures between 15 °C and 20 °C are the most conducive to fungus spread that can result in the development of new, more virulent powdery mildew races in as little as 7 to 10 days [218, 219].

Wheat can exhibit either racial-specific or non-racial-specific resistance to powdery mildew. Single resistance (R) (main impact) genes produce race-specific resistance, which is heritable and provides complete resistance to some specific diseases but not others. Non-race-specific resistance confers partial resistance that does not depend on the pathogen virulence gene and permits infection while inhibiting pathogen proliferation [220, 221]. However, long-term survival pressure and environmental cues have endowed infections with outstanding adaptability [222], resulting in substantial pathogen diversity [223]. Multiple race-specific resistance genes inserted in wheat cultivars may quickly evolve and appear because the wheat interaction is host or race-specific [207]. As a result, more new virulent races may not be effectively prevented from developing. Therefore, it is essential to research novel wheat powdery mildew resistance genes to create long-lasting preventive and therapeutic strategies for this disease. To further strengthen resistance to powdery mildew, it is essential to elucidate the underlying regulatory mechanisms of bread wheat defense responses to biotic stressors [224].

1.10.3. Current disease management strategies

Several methods can control powdery mildew disease. Fungicide application is typically chosen among them all. Still, the disease quickly develops chemical resistance, though it can be expensive to use and has a detrimental effect on the environment and human health. However, using appropriate fungicides and timely application, coupled with using the resistant variety, is the most effective control strategy. In this situation, powdery mildew disease resistance types are developed using traditional and next-generation breeding approaches. More than 100 powdery mildew resistance genes, including 68 that were previously mapped on various chromosomes, have been described in wheat and its relatives because of numerous investigations to identify resistance genes [75, 225, 203, 226, 227, 228].

1.11 Economic parameter estimates in spring wheat

In modern agriculture, the economic viability of cultivation technologies plays a pivotal role in farmers', researchers', and producers' decision-making. The selection of cultivation technologies directly affects costs, yield, and profitability. Economic parameters estimation analysis is crucial in any farming system, including spring wheat cultivation. The assessment and evaluation of different cultivation technologies for spring wheat production emphasize calculating costs, benefits ratio, and potential returns, not forgetting the breakeven point and payback period in any farming enterprise. Cultivation technologies encompass a range of practices, from seed selection to harvest management practices, up to the final consumers. Choosing the appropriate technology can significantly influence a farm's financial performance [229]. Economic analysis provides a systematic framework for comparing various cultivation methods, enabling farmers to make informed choices that maximize returns while minimizing costs [230]. A practical economic analysis involves a comprehensive evaluation of the financial aspects associated with different cultivation technologies. On that note, the following components of economic parameter estimate analysis are crucial:

Input costs: This includes expenses related to seeds, fertilizers, pesticides, machinery, labor, and irrigation. Different technologies may require varying input levels, impacting overall costs [231].

Yield potential: Assessing each technology's yield potential is crucial, as higher yields contribute directly to revenue. Historical data, field trials, and research can help estimate yield variations. Consequently, yield potential and stability cannot be determined from a solitary field experiment completed inside a single year; they necessitate an assessment derived from yield measurements gathered over three to five years and locations. Consequently, yield stability is estimated using various statistical methods that model variability across different environments [232].

Market prices and quality premiums: Understanding market prices for spring wheat is essential for estimating potential revenue. Prices can vary based on quality, demand, and global market dynamics. Using appropriate cultivation technologies may result in higher grain quality, leading to price premiums in the market. Higher protein content, better kernel size, and reduced mycotoxin levels are examples of quality factors that can influence prices [233].

Risk management: Risk factors, such as disease incidence and weather fluctuations, must be considered when evaluating cultivation technologies. Technologies that offer risk mitigation can indirectly impact profitability [231].

Operational efficiency: Technologies that improve operational efficiency, reduce downtime, or enhance resource utilization contribute to cost savings and higher returns. Furthermore, the steps in economic parameters analysis should be followed accurately [234].

i) **Data collection** is an information gathering to ensure the data's accuracy, completeness, quality, and usefulness. Data should be collected on input costs, expected yields, market prices, quality premiums, and other relevant factors for each cultivation technology [235].

ii) **Cost analysis:** Calculate the total costs associated with each technology, including variable and fixed costs. Variable costs fluctuate with production levels, while fixed costs remain constant [236].

iii) **Revenue projection:** Estimate potential revenue by multiplying expected yield with market prices. Include any additional revenue from quality premiums.

iv) **Net return:** Subtracting the total profit from the total expenses, then divide by the initial production cost, multiply by 100 percent to determine the net return for each cultivation technology -: (Net Return = Total Profits or Gains – Total Expenses / Initial Investment x 100) [231].

v) **Sensitivity analysis**: Assess the impact of potential yield variations, market price fluctuations, and other uncertainties on net returns [232].

vi) **Decision making and implementation**: Based on economic analysis, farmers can identify which cultivation technology offers the highest potential for profitability. Consideration of risk tolerance, available resources, and long-term sustainability is essential when making a final decision [236, 231].

Long-term considerations: It's essential to think about short-term profits, but you should also think about long-term factors like soil health, sustainability, and the impact on the environment while choosing technology. Long-term profitability can come from sustainable measures that keep soil fertility and natural resources intact. So, economic analysis is very important for selecting and evaluating cultivation technology for growing spring wheat. By systematically assessing costs, benefits, and potential returns associated with different technologies, farmers can make informed decisions that optimize their financial performance while aligning with their farm's goals and values. This approach ensures that cultivation technologies contribute to short-term profitability and promote long-term sustainability and success [235, 229, 232].

Spring wheat, originating in the Fertile Crescent, is a globally vital cereal crop valued for its adaptability, nutrition, and economic importance. Its production faces threats from diseases, which reduce yield and grain quality. Effective management requires integrated strategies, resistant varieties, sound agronomy, balanced fertilization, crop rotation, and timely fungicide use.

CHAPTER TWO

MATERIALS AND METHODS

2.1 Description of study area

Field experiments were conducted over three years during the spring wheat cropping seasons starting from May 2022 to 2024 each year, at the Technological Center of Agriculture of the Federal State Budgetary Institution Federal Research Center "Nemchinovka," situated in Sokolovao village, Novomoskovsky AO, Moscow, Russia. The experimental site is located at 55°45'N, 37°38'E, at an elevation of 200 meters, characterized by sod-podzolic, medium loamy soil. The three-year field research trials were established in a field where crop rotation, utilizing diverse cultivation techniques and the cultivation of alternating crops such as grain legumes, oats, potatoes, cotton, and barley, is cultivated as a precursor crop for the experimental field (Figure 2.1).

Figure 2.1. The field experimental site at Nemchinovka, Moscow

2.2. Soil analysis and physico-chemical characteristics of the soil before planting (2022, 2023, and 2024)

The soil at the experiment field is a medium loamy, well-drained sod-podzolic soil. A Jarrett T-handle soil auger with a 100 mm head diameter was utilized to randomly collect fresh subsoil samples from 0 to 30 cm deep prior to planting. These samples were then combined into composite samples, following the methodology by [237] for soil analysis in the laboratory. An agrochemical survey of the experimental plot was conducted at the beginning of each growing season (before sowing) from 2022 to 2024. The soil on the experimental plot in 2022 was categorized as sod-podzolic, medium loamy, and positioned on a moraine complex with a slope of up to 10% that was somewhat acidic. The arable horizon was 25 to 28 cm thick, and the organic matter concentration was between 3.0% and 4.0%. The pH of the soil was between 5.7 and 5.8, which is slightly acidic and close to neutral. The hydrolytic acidity was 3 ml eq per 100 g of soil, which means it was moderately acidic. Mobile P_2O_5 (phosphorus) content, as measured by the Kirsanov method, was high at 162-195 mg/kg. Exchangeable K_2O (potassium) was at an average level of 86-122 mg/kg.

In 2023, the soil type remained the same as in 2022, with a similar moraine complex and a slight acidity of up to 10%. The thickness of the arable horizon was slightly thicker, ranging from 26 to 28 cm, compared to 25 to 28 cm in 2022. The organic matter content increased somewhat, from 3.2% to 4.1%. The soil pH consistently measured between 5.7 and 5.8 (slightly acidic, near neutral), but hydrolytic acidity remained stable at 3 ml eq per 100 g of soil. The mobile P_2O_5 concentration, as reported by Kirsanov, was 165-193 mg/kg, reflecting a minor decline from the 2022 range of 162-195 mg/kg. In contrast, exchangeable K_2O exhibited a slight rise, varying from 80 to 119 mg/kg on average.

The experimental plot showed a noticeable increase in exchangeable mobile P_2O_5 (214-236 mg/kg) and exchangeable K_2O (126-140 mg/kg) in 2024. The soil remained slightly acidic, with a pH range of 5.1 to 5.2, lower than in 2022 and 2023. The organic matter content increased slightly from 3.3% to 4.2%.

2.3. Meteorological conditions of the experimental site (2022-2024)

The meteorological conditions at the experimental site from 2022 to 2024 were recorded using weather stations at the Federal Research Center 'Nemchinovka,' which is part of the Federal State Budgetary Institution. All weather data were collected there. From March to August, we calculated the average temperatures and total precipitation for each growing season (Figure 2.2).

The observed readings from the weather station in 2022 show that March experienced relatively cooler temperatures (-1.2°C); nevertheless, the weather slowly warmed up, reaching a high of 22.3°C in August. In 2023, March saw milder conditions (1.3°C) and maintained a moderate climate throughout the growing season, peaking at 19.7°C in August. However, 2024 recorded slightly warmer temperatures in March (0.8°C) and a notable increase in June (19.6°C) and July (21.9°C), followed by a slight decrease in August (18.6°C).

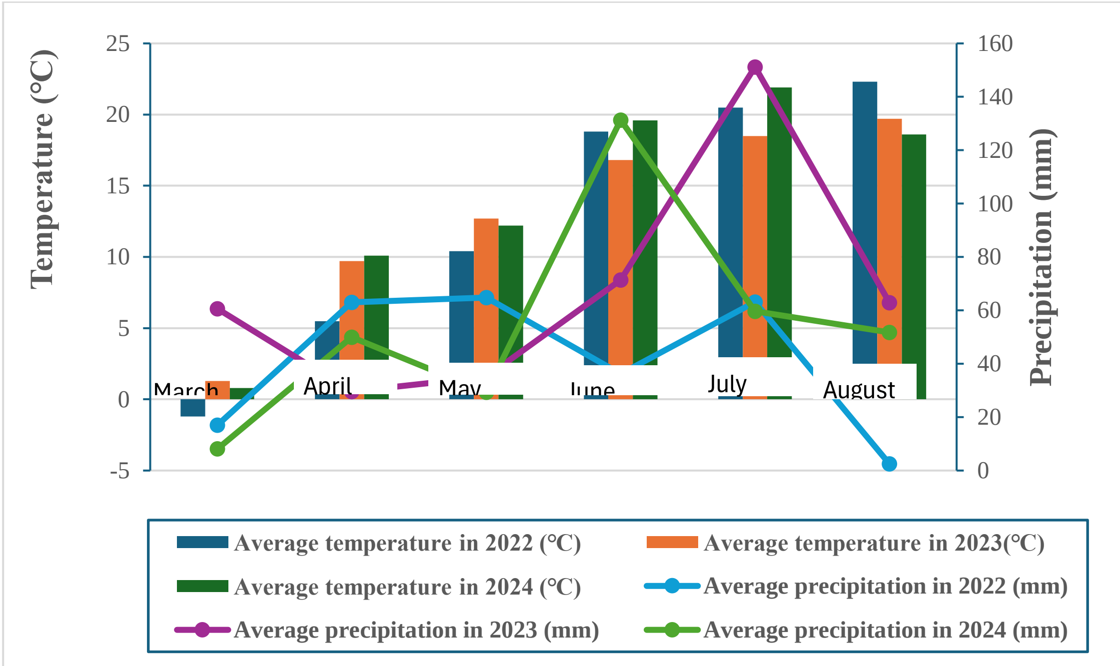


Figure 2.2. Meteorological Data 2022-2024 (Nemchinovka weather station)

Rainfall levels were moderate, with the most significant precipitation occurring in April (63.0 mm) and July (63.1 mm), but August was notably dry (2.5 mm) in 2022. In contrast, 2023 experienced high precipitation levels, particularly in June (71.4 mm) and July (151.2 mm). This led to waterlogging and excess moisture, affecting some plants in some regions of the trial plots. For the year 2024, precipitation remained moderate in April (49.9 mm) and May (29.4 mm), but June (131.3 mm) and July (59.7 mm) showed a significant amount of rainfall, similar to the weather conditions of 2024. Overall, the moderate temperatures and balanced rainfall noted in April, May, and July 2022, along with the continued dryness in August, were essential for successful harvesting. Nevertheless, the colder March resulted in delays in planting, and the dry conditions in August put slight stress on the crops due to a lack of water. In 2023, temperatures remained milder throughout the growing season; however, the excessive rain in June and July (71.4 mm and 151.2 mm, respectively) led to issues like plant logging and increased disease incidence, thus reducing crop yields. In 2024, we observed moderate warm temperatures in June and July, which were advantageous for key growth stages. However, a higher rainfall was observed in June (131.3 mm), and the moderate levels in July (59.7 mm) resulted in similar problems as in 2023, such as logging of wheat plants in some regions of the experimental site and instances of disease, although not as severe. It was observed that the 2022 cropping season was the most favorable for spring wheat due to its moderate temperatures and balanced precipitation despite the colder March and dry August. In contrast, 2023 and 2024 were less advantageous due to excessive rainfall during critical growth stages of the crop in June and July, which could adversely affect yields.

2.4. Experimental materials

Three spring wheat cultivars (Radmira, Belyana, and Agros) were used for our research study, of which Radmira is an improved, released, registered variety in the Russian Federation called a standard variety. It was used as the check variety, and the Belyana and Agros varieties are novel (advanced breeding lines), all referred to as cultivars (Table 2.1). These planting materials were bred and obtained from the Federal State Budgetary Institution Federal Research Center at 'Nemchinovka,' Moscow region, Russia.

Table 2.1– Description of genotypes utilized for the study

N°	Genotypes	Variety code	Status	Pedigree
1.	Belyana	8057532	Breeding line	Engelina × Ester
2.	Agros	7852652	Breeding line	Zlata × Moskovskaya 56
3.	Radmira	8261389	Standard variety (use as a check variety)	Zlata × Ester

Description of Radmira variety:

Radmira belongs to soft spring wheat, and its Pedigree is derived from a hybrid population (Zlata and Ester) variety. Radmira is a registered cultivar listed in the State Register for the Volga-Vyatka (4) region, and it has been recommended for cultivation in the Nizhny Novgorod region. This variety was used in this study as a check variety. Radmira is a semi-erect wheat with medium-length straw. The straw is weak, with a light wax coating on the ear, flag leaf sheath, and upper straw internode. Its ear is Pyramidal, medium density, white, with short awn-like processes. The stems are rounded-straight, narrow to medium width. Radmira has a fine-grain color, and the weight of 1,000 grains is estimated to range between 32 and 41 g. Its average regional yield has been reported to reach 30.8 c/ha. Yield in the Nizhny Novgorod region has increased by 3.0 c/ha over the Ulyanovskaya 105 standard, reaching 40.6 c/ha. There has also been a report of a maximum yield recorded at 80.6 c/ha in 2019 in the Nizhny Novgorod [238]. Radmira is a mid-season crop with a vegetation period of 76-107 days, ripening 2-3 days earlier than Ulyanovskaya 105. It exhibits strong lodging resistance and is drought-tolerant, with a slightly lower rating than Ulyanovskaya 105 by up to 1.0 points. Radmira variety upon sample testing, it shows moderate resistance to wheat diseases like powdery mildew and brown rust. Its baking quality has been reported to be good. This variety originated and was developed by the Nemchinovka Federal Research Center, Moscow Region [238].

Description of the Belyana variety:

Belyana is a novel soft spring wheat breeding line; its Pedigree originated from (Angelina and Ester). The Belyana variety was bred by individual sections from the F5 hybrid population (Angelina × Ester). The maximum yield of the Belyana variety has been estimated to reach 42.0 c/ha when it was under testing. This variety is resistant to lodging, and it is estimated at 9 points on a 9-point scale. Also, in ecological variety testing by the Federal Research Center "Nemchinovka" when grown using intensive technology, the yield reached 85.5 c/ha, and the average yield over 3 years was 59.8 c/ha, as compared to the Zlata standard (56.1 c/ha). Belyana is also resistant to smut diseases, septoria, and brown rust, as well as stem rust, to a higher degree than most standard varieties like Zlata. The variety is mid-season, as evidenced by its display in early May, and economic maturity is achieved under the conditions of Vladimir Opolye in August. The variety has red, large grains with higher technological and baking indicators (compared to the standard). The new variety has higher indicators than the Zlata variety: grain vitreousness (72%), crude gluten content (38.4%) and crude protein (16.3%), alveograph index (337 U.A.), valorimetric assessment (64 U.val.), falling number (439 sec.), bread porosity (4.0 points), volumetric bread yield (1027 ml), overall quality assessment (4.7 points). The Belyana variety is a high-yielding variety that has good grain quality at the level of valuable wheat and high resistance to lodging and diseases. Belyana variety can be grown under conventional and intensive technologies. Upon testing, the belyana variety was well adapted to intensive technologies (intensification of agricultural practices), while increasing the intensity of cultivation technologies ensured greater productivity. The patent holders of the Belyana variety are the Federal Research Center Nemchinovka, Federal Research Center, and Verkhnevolzhsky Federal Agricultural Center [238].

Description of the Agros variety

Agros is a novel (breeding line variety, a soft spring wheat, and its Pedigree is obtained from Hybrid varieties (Zlata and Moskovskaya 56). Its registration has been included in the State Register for the North-West (2) and Central (3) regions, recommended for cultivation in the Vologda and Tver regions. Agros' structure is semi-erect, has an intermediate bush form, and has a medium plant height. The straw strength is weakly formed, with an average wax coating on the upper internode and ear and a strong wax coating on the flag leaf sheath. The ear structure is characterized by a pyramidal shape, medium density, and white color, with very short awn-like features. The stem is rounded and straight, with a medium width. It has an attractive grain color, and the weight of 1.000 grains is reportedly between 39-47g. Its average regional yield has been estimated to reach 33.4 c/ha in the northwest and 36.2 c/ha in the Central regions. In the Tver and Vologda regions, yield has been approximated to achieve a 5.9 c/ha increase over the Sudarynya standard in the Tver region and Vologda, comparable to the Zlata standard, with yields of 27.0 c/ha and 42.2 c/ha. It was also reported that a maximum yield of 61.9 c/ha was achieved in 2022 in the Tula region. Agros variety is a mid-early crop with a vegetation period of 83-92 days; it can ripen 2-3 days later than the Zlata standard (Figure 2.3 and Table 2.1). Agros has strong lodging resistance and better drought resistance. This variety is moderately resistant to powdery mildew, slightly susceptible to common smut and brown rust, and moderately susceptible to septoria. It has a perfect baking quality, hence classified as valuable wheat. This variety originated and was developed by LLC 'NADEZHDA,' Moscow (109147, Moscow, Vorontsovskaya) [238].

Figure 2.3**.** The three varieties used in the study

2.5. Experimental layout, design, treatment, and management

The Field trials were carried out over three cropping seasons, spanning from May 2022 to 2024. The experimental plot area measured 20 m × 4 m (80 m²), using an intra-plot spacing of 1.0 m and an inter-block spacing of 1.0 m. Each block was replicated, consisting of 9 plots, resulting in a total of 27 field plots. The nine plots in each replication consisted of three varieties and three cultivation technologies (Table 2.2). The experiment utilized a 3 × 3 factorial design arranged in a split-block design, comprising three replications. A basic cropping system is an agricultural production approach that employs reduced variable inputs, such as labor, fertilizers, and pesticides. The basic cropping system typically denotes traditional agriculture in low-productivity regions, but it may also pertain to small-scale wheat farming. An intensive cropping system is defined as the additional application of inputs, including labor, pesticides, and fertilizers. Table 2.5 presents the specifics of the inputs utilized in the experiment's tested technologies. The experimental field was plowed before seed sowing and subsequently prepared through roller harrowing. A pre-sowing seed treatment with Oplot Trio (500 mL ha-1) was applied before planting, following the standard operating manual [239]. The cultivation of the treated spring wheat seeds was done using an Amazon D9-40 seeder. The treated seeds were sown at a depth of 4-5 cm utilizing a rolling Katros machine. Harvesting was conducted utilizing a combined harvester, specifically the "Sampo 500".

2.5.1. Description of the cultivation technologies

The study formulated three levels of cultivation technologies to assess their influence on three soft spring wheat varieties with varying intensity levels.

High-intensive technology- is a technology formulated to obtain maximum production of high-quality grain that compensates for losses resulting from harvesting that can cause nutrient depletion, recovering monetary benefit, energy, and labor expenses, utilizing the latest generation of high-yielding varieties, and ensuring total protection of crops against pests, diseases, and weeds, and application of fertilizer. This strategy maximizes the potential of the variety by over 85% and keeps the labor input at less than 3.0 man-hours. The technologies are used under favorable environmental and climatic conditions, and these are a collection of processes (technologies) that achieve 85-90% or more of the variety's potential for productivity and quality. Their application involves the application of standard mineral fertilizer levels using diagnostics at different phases of plant growth, implementing plant protection systems against diseases and pests, forecasting these diseases and pests, integrating monitoring, employing innovative treatments, and leveraging the latest technology and equipment, among others.

Table 2.2 – Treatments used in different cultivation technologies

No.	Technique	Basic Technology	Intensive Technology	High-Intensity Technology
1	Basic application, kg/ha (Fertilizer)	N30P40K90	N30P60K120	N30P90K150
2	Top dressing, kg/ha (Fertilizer)	N30	N30	N30 + N30 (based on diagnostics)
3	Seed treatment	Oplot Trio — 0.5 l/t	Oplot Trio — 0.5 l/t	Oplot Trio — 0.5 l/t
4	Herbicide treatment (tillering phase)	Balerina — 0.5 l/ha + Fides — 0.4 l/ha	Linur — 0.16 kg/ha + Puma Super 100 — 0.6 l/ha	Linur — 0.16 kg/ha + Puma Super 100 — 0.6 l/ha
5	Insecticide treatment (stem elongation phase)	Borey Neo — 0.2 l/ha	Decis Expert — 0.03 kg/ha	Decis Expert — 0.03 kg/ha
6	Fungicide treatment (stem elongation phase)	Kolosal Pro — 0.4 l/ha	Kolosal Pro — 0.4 l/ha + CHEFK — 0.8 l/ha	Kolosal Pro — 0.4 l/ha + CHEFK — 0.8 l/ha

Intensive cultivation technology- is a cultivation technique aimed at attaining high-quality grain as well as mitigating nutrient loss caused by harvesting, protecting crops from various wheat diseases, pests, and weeds, and ensuring that the variety's potential is realized at over 65% -75%. Intensive technique requires less than 4.5 man-hours of labor per ton of grain produced, with an estimated yield of 5.0-5.5 t ha^{-1}.

Basic Cultivation technology, on the other hand, focuses on harvesting by optimizing soil fertility and utilizing agricultural landscape resources. It achieves over 50% of a plant variety's biological potential but requires 6.5 man-hours of labor per ton of grain and secures a harvest of 3.0-3.5 t ha^{-1}. Presently, there are intentions to develop software that will facilitate the implementation of these technologies. This program will assist any farmer in selecting and implementing the most effective technology for their operation.

2.6. Plant sampling

In plant sampling methods we utilized the 0.5 m^2 rectangular quadrat (1.25 m × 0.4 m) orientated diagonally where possible or parallel to the crop to be sampled for more representative sampling [240], for growth and development indicators, including randomly 25 plant samples were collected for all yield traits. In collecting and analyzing for disease prevalence and the degree of development, 50 plants per plot and per replication for each disease were used as sample. The quality indicators (gluten and protein) contents were analyzed and determined using the harvested grains form each treatment and replication in the laboratory. These plants were selected randomly from within the quadrat area. The plant samples were carefully pulled up manually with hands when the soil conditions were somewhat moist. This was done to ensure that the structural plants, stems, and spikes and spikelets did not break or lose their grains during sampling. Tagging of all plant samples collected were done according to treatment trials, and they were tied, and stored at 4°C at the Federal Research Center, "Nemchinovka" laboratory, until all parameters were analyzed (see Figure 2.4).

Figure 2.4. Field data collection

2.7. Collection of samples and disease assessment

During the following growing seasons, 2022, 2023 and 2024, a total of 50 wheat leaves and 50 wheat spikes from each cultivar within each replicated plots were collected during the following growth stages (GS) of wheat development: stem elongation (GS 30 - GS39), booting (GS 40 - GS 49), heading and flowering (GS 50 -GS59 and GS60 - GS69), the late milk to early dough development stages (GS 70 -89), and ripening and maturity (GS 90-GS99) to assessment three key wheat diseases (fusarium head blight, Septoria leaf blotch, and powdery mildew) incidence and severity. Hence, during the study, disease incidence refers to the proportion or percentage of plants (or plant parts) affected by a disease in each area. The incidence in plant epidemiology measures the widespread disease within the field. Disease incidence is commonly used for early disease detection and surveillance. Incidence is essential because it gives informed decision-making for disease management, such as when the farmer needs to apply fungicides. The disease severity refers to the extent or degree of damage caused by the disease on infected plants or plant parts. It quantifies the severity of plant impact rather than just the number affected, and it is often assessed using a disease rating scale (Table 2.7). Disease severity helped assess yield loss potential and the economic impact of the disease. The assessment of 50 plant samples was evaluated in each replicated plot (150 plants per cultivar) throughout the yearly monitoring periods. Fusarium head blight disease prevalence (incidence) and severity were visually evaluated on 50 heads per cultivar and per treatment. The prevalence of FHB disease was measured as the percentage of heads in each treatment plots showing symptoms. At the same time, disease severity (DS) was enumerated as the extent of damage, expressed as the percentage of spikelets per head exhibiting bleaching. The evaluation of disease severity was assess based on the proportion of infected spikelets per head using the FHB disease rating scale (Table 2.7). The FHB incidence and severity were calculated using the following formulas [241;242].

$$\text{Disease Incidence (\%)} = \frac{\text{Number of spikes with symptoms}}{\text{Total number of samples assessed}} \times 100$$

And

$$\text{Disease Severity (\%)} = \frac{\text{n} \times \text{v}}{5\text{N}} \times 100$$

Where (n) = Number of spikes in each category, (v) = Numerical values of the symptoms category. (N) = Total number of spikes, (5) = Maximum scale.

The evaluation of foliar diseases commences at the beginning of GS30 (stem elongation), up to (SG70-89) milk-dough development stage for Septoria leaf blotch, powdery mildew prevalence and they were assess as the (percentage of plants with the disease symptoms), and severity was assess as the (percentage of leaf area with high symptoms showing pycnidia). At each sampling date, portions of each are evenly distributed at intervals throughout the sampling regimes. Visual estimates of the areas covered by both sporulating *S. tritici* lesions and naturally senescent tissue, and for powdery mildew percentage of stem or leaf area covered with necrosis were made on each of the uppermost leaves and each stem following a similar pattern of disease rating scale (0-5), Table 2.3, and Figure 2.5. All disease samples were taken from the five internal rows of each plot during the assessment periods. The disease scoring was terminated when the wheat crops reached physiological maturity, approximately at the GS of 99 [243].

Table 2.3 - Disease rating scales for Fusarium head blight (FHB) [24; 242].

Scale	**Description of the symptoms**
0	Spikelets free from bleached
1	Small Spikelet discoloration covering <5% spike
2	Small irregular bleached florets with concentric rings covering 5.1-10% spikelets
3	Enlargement of infected spikelets that have developed pink, orange, or salmon-colored fungal spores covering 10.1-25% spikelets
4	Premature ripening: Spikelets ripen early, resulting in shriveled, lightweight, and discolored grains as a typical blight symptom covering 25.1- 50% of the spike
5	Enlargement of irregular dark Brown Lesions covering a typical blight symptom covering > 50% of spikelets

Figure 2.5. Field diseases assessment and rating

2.8. Field and Lab data collection and analysis

A total of 14 agro-morphological traits were collected. Data collection was based on protocols presented in the descriptor for maize variety performance evaluation trial [244] with slight modifications (Table 2.8); Figure 2.8. represents field and lab data analysis. The disease severity score values for septoria leaf blotch (SLB) (*Septoria tritici*), powdery mildew (PM), and fusarium head blight (FHB) were converted to percentages and then used to estimate the area under disease progress curves (AUDPC) as described by [242].

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2}\right)(t_{i+1} - t_i)$$

where y_i = disease severity at the i observation, t_i = time (days) at the i observation, and n = total number of observations. The susceptibility scale values of SLB, PM, and FHB were estimated by first calculating the resistance scale values described by [242]. $S_x = S_y \frac{D_x}{D_y}$ where S_y = the assigned susceptibility scale value, D_y= observed disease score (AUDPC or rAUDPC) for the standard genotype, S_x= estimated susceptibility scale value, D_x= Observed disease score for the studied variety and rAUDPC = relative AUDPC. The quotient of the assigned susceptibility value and the check variety's resistance measure (AUDPC or rAUDPC) was used to obtain a constant. The resistance value of each variety was then multiplied by the constant to get the susceptibility value of that variety. Protein content was determined using the micro-Kjeldahl method (N × 6.25) [245].

Figure 2.6. Laboratory analysis

Table 2.4 - Phenotypic traits measured in three spring wheat genotypes

SN	Trait descriptor	Trait acronym	Score code /descriptor state	Sample/time collected
Vegetative traits				
1	Plant height (cm)	PH	direct measurement using a meter rule	on 10 plants at 1 MAP
2	Number of stems/plants	NSP	direct measurement: done by counting	on 0.5m^2 area at harvest
3	Number of plants/0.5m^2	NP	direct measurement: done by counting	on 0.5m^2 area at harvest
Disease traits				
4	Septoria leaf blotch severity score	SLB	1=no visible symptoms of disease; 2=mild; 3=low; 4=intermediate; 5=high	on 50 plants at PGS

5	Powdery mildew severity score	PM	1=no visible symptoms of disease; 2=mild; 3=low; 4=intermediate; 5=high	on 50 plants at PGS
6	Fusarium head blight severity score	FHB	0=no visible symptoms of disease; 1=<.5%; 2=5.1-10%; 3=10.1-25%; 4=21.1-50%; 5=>.50%	on 50 plants at PGS
Grain yield and quality traits				
7	Length of spike per plant (cm)	LSPP	direct measurement: done using a meter rule	On 25 plants at 1 WAH
8	Number of spikelets per spike (cm)	NSPS	direct measurement: done by counting	On 25 plants at 1 WAH
9	Number of seeds per spike	NSS	direct measurement: done by counting	On 25 plants at 1 WAH
10	Weight of seed per spike (g)	WSS	direct measurement: done using an electronic scale	On 25 plants at 1 WAH
11	Weight of 1000 seeds (g)	WTS	direct measurement: done using an electronic scale	On 1000 grains at 2 WAH
12	Grain yield (t ha^{-1})	GY	direct measurement (derived estimate)	At harvest (4 MAP)
13	Gluten content (%)	GC	direct measurement (derived estimate)	After harvest (1 MAH)
14	Protein content (%)	PC	direct measurement (derived estimate)	After harvest (1 MAH)

WAH=weeks after harvest, PGS=plant growth stages, MAP= months after planting

2.9. Economic parameters studied in the experiment

Economic parameters in wheat production are important cost and efficiency factors used to evaluate the profitability, productivity, and sustainability of a wheat farm. These parameters help farmers, scientists, and policymakers assess farm performance, optimize resource use, and make informed choices. This allows farmers to improve financial decisions, better utilize inputs, and maximize farm productivity while staying economically viable (Table 2.5).

Table 2.5. Abbreviations, formulae, and units of different economic parameters studied in the experiment

Parameters	Abbreviation	Formula	Unit
Grain yield	GY	GY $m^{-2} \times 10,000$	kg ha^{-1}
Partial factor productivity of Nitrogen	PFP_N	GY ha^{-1} ÷ rate of applied	kg grains kg^{-1} N
Partial factor productivity of Phosphorus	PFP_P	GY ha^{-1} ÷ rate of applied	kg grains kg^{-1} P
Partial factor productivity of Potassium	PFP_K	GY ha^{-1} ÷ rate of applied	kg grains kg^{-1} K
Agronomic Efficiency of Nitrogen	AE_N	GY_{IOC} ÷ rate of N applied	kg grains kg^{-1} N
Agronomic Efficiency of Phosphorus	AE_P	GY_{IOC} ÷ rate of P applied	kg grains kg^{-1} P
Agronomic Efficiency of Potassium	AE_K	GY_{IOC} ÷ rate of K applied	kg grains kg^{-1} K
Grain yield value	GY_V	GY ha^{-1} × value of grains kg^{-1}	Rub. ha^{-1}
Increase in GR over control	GR_{IOC}	GR – cost that varies (CostV)	kg ha^{-1}
Net returns	NR	GR_{IOC} – CostV	Rub. ha^{-1}
Value-cost ratio	VCR	GR_{IOC} ÷ CostV	Rub. ha^{-1}
Marginal returns	MR	NR ÷ CostV	Rub. ha^{-1}
Payback period	PBP	Investment value ÷ advantages of each production system	
Breakeven point	BEP	Total production cost ÷ selling price	t or kg
Nitrogen-cost	NC	Price per bag ÷ N content in a bag	Rub. ha^{-1}
Phosphorus-cost	PC	Price per bag ÷ P content in a bag	Rub. ha^{-1}
Potassium -cost	KC	Price per bag ÷ K content in a bag	Rub. ha^{-1}

To determine the above, a cost-benefit analysis was conducted for the intended cultivation technologies, including the resistance, yield, and grain value of wheat varieties, as well as chemical seed treatments, agronomic efficiency, and partial productivity factor. The procedure suggested by [230] was employed. Hence, the study evaluated and analyzed 15 economic parameters determined by wheat grain yield. These economic parameters include grain yield (GY), partial factor productivity of nitrogen (PFPN), Phosphorus (PFPP), and Potassium (PFPK), increase in gross returns over control (GRioc), agronomic efficiency of Nitrogen (AEN), Phosphorus (AEP), and Potassium (AEk), grain yield value (GYV), net return (NR), value cost ratio (VCR), and marginal return (MR), Cost that varies (CostV), payback period (PBP) and breakeven point (BEP) (Table 2.5).

2.10. Statistical Data Analysis

Data were subjected to analysis of variance (ANOVA) using the GENSTAT statistical program (GENSTAT, 15th release, Rothampstead, UK). The Student Newman-Keuls multiple range test (SNK) was used to compare treatment means using a significance level of $\alpha = 0.05$. The data residuals for the parameters were first checked for normality and homogeneity using Shapiro-Wilk and Bartlett's tests to ensure that data are normally distributed. Partial Factor Productivity (the ratio of the grain yield to the applied rate of fertilizers) and Agronomic Efficiency (the ratio of the increase in grain yield over fertilizer-control plots to the applied rate of fertilizer) were determined according to the procedures described by [246]. Other economic analyses were also estimated, such as value cost ratio, net returns, and marginal return, among others.

CHAPTER THREE

3.0 YIELD COMPONENTS, YIELD, AND QUALITY TRAITS OF SPRING WHEAT VARIETIES UNDER DIFFERENT CULTIVATION TECHNOLOGIES (2022–2024)

3.1 Yield Components

To improve spring wheat productivity, a study was conducted to evaluate the impact of two novel spring wheat varieties (Agros and Belyana) and one standard variety (Radmira), in combination with three cultivation technologies, on growth parameters, yield, and quality traits.

3.1.1. The influence of varieties and cultivation technologies on plant height

The pooled data on plant height were subjected to analysis of variance, revealing statistical significance ($P < 0.001$), which highlights the varietal effect on plant height. The height of plants plays a crucial role in wheat development and yield, influencing morphogenesis and grain production. Analysis of variance in the 2022 growing season shows that the Agros variety had the tallest plant height (92.53cm). Radmira and Belyana, on the other hand, had shorter plants with average heights of 82.70cm and 79.5cm, respectively. In 2023, a similar trend occurred, with the Agros variety attaining the tallest plant height (125.74 cm), followed by Radmira (114.66 cm). In contrast, in 2024, the Radmira variety shows the tallest plant height (132.54 cm). However, the average for the three years shows that the Agros variety exhibited the tallest plant height of (116.53 cm), surpassing both the standard (Radmira) and Belyana with a percentage increase of (± 5.63). These variations within years could be due to the differences in their genome variation, physiological traits, nutrient use efficiency, disease occurrence, and environmental factors. The results support the notion [247, 248, 249, 250] that within the same wheat field, factors such as soil fertility, moisture retention, disease pressure, and genotype differences can result in variations in nutrient use efficiency, morphogenesis, and other genetic traits of the plant (Table 3.1).

Table (3.1) –The influence of three varieties and three cultivation technologies on plant height and spike length of spring wheat

Treatments	Plant height			Three years Average	± Basic (%)	Length of Spike			Three years Average	± Basic (%)
	2022	2023	2024			2022	2023	2024		
Main Plot: Cultivation Technology										
Basic	78.00	112.24	129.28	106.51	-	9.63	8.09	9.04	8.92	-
Intensive	90.40	115.81	132.65	112.95	6.05	10.77	8.96	9.13	9.62	7.84
High -intensive	86.00	117.59	128.04	110.54	-2.13	10.87	8.99	8.88	9.58	7.40
P-value	<.001***	0.05*	0.001**	-	-	0.003*	0.074ns	0.230ns	-	-
LSD 5%	0.34	4.1	1.22	-	-	0.44	0.86	0.34	-	-
Standard error (A)	0.15	1.81	0.54	-	-	0.20	0.38	0.15	-	-
CV%	0.2	1.6	0.4	-	-	1.9	4.4	1.6	-	-
Sub plot: Varieties										
Agros	92.53	125.74	131.31	116.53	5.63	10.00	8.27	8.98	9.08	-7.44
Belyana	79.53	105.24	126.12	103.63	-5.76	10.37	8.25	9.05	9.22	-6.01
Radmira (Standard)	82.7	114.66	132.54	109.97	-	10.90	9.51	9.03	9.81	
P-value	<.001***	<.001***	0.002*	-	-	<.001***	<.0.008**	0. 795ns	-	-
LSD 5%	0.64	2.05	2.03	-	-	0.09	0.64	0.29	-	-
Standard error (B)	0.28	0.90	0.90			0.04	0.28	0.13		
CV%	0.3	0.8	0.7	-	-	0.4	3.2	1.4	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the mean, *** =highly significant, ** = very significant, * =significant, ns =not significant.

Cultivation technology also exhibits significant variance ($p < 0.001$) in its influence on plant height over the three years. The basic technology shows the shortest plants an average of 106.51 cm; however, increasing the farming inputs by introducing Intensive technology, plant height shows (112.95cm), while High Intensive was (110.54cm). Analysis shows that a dramatic increase across all varieties was evident with the Intensive system (±6.05 %) compared to the basic system. The highest plant height was observed in 2024 with intensive technology (132.65 cm). However, when a high-intensive production system was evaluated, the results showed a decrease in plant height from 132.65 to 128.04 cm in 2024. Although high input investment improves plant height, our research has revealed that beyond a certain threshold of production intensity, the plant height of wheat starts to decrease, as demonstrated by the high-intensive cultivation technology (Table 3.1), which resulted in a (± 2.13 cm) drop in plant height. Our findings have shown that using the appropriate inputs, combined with hybrid varieties, is essential for enhancing wheat growth and development. The research findings are in analogy with [65, 67, 68, 251, 252], stating that despite significant advancements in wheat grain yield through breeding initiatives, it is imperative to integrate superior genotypes with enhanced agronomic practices and physiological characteristics linked to high yield, derived from complementary and genetically diverse genetic resources.

The results obtained in the study conform to the established concept that plant height is a heritable trait. The plant height genes are likely to be dominant in the Agros variety, resulting in taller plants than those in the Belyana and Radmira varieties. Furthermore, plant height traits are influenced by external factors such as the agricultural techniques employed in this research. This explained the increase in height resulting from the production techniques employed, ranging from basic technology to intensive and high-intensive technology. Following the law of diminishing returns, which states that with increasing production, Ceteris Paribus, production will reach a threshold beyond which an additional increase will lead to a progressive decline in output; hence, the plant height decreases as the high-intensive cultivation technology was introduced. Our findings suggest that Agros and intensive cultivation technology could be essential for increasing wheat plant height, as this trait is crucial for wheat breeders and policymakers in wheat value chain systems.

3.1.2. The influence of varieties and cultivation intensities on the spike length per plant

Our ANOVA analysis reveals a statistically significant varietal effect on spike length per plant (P < 0.001) in 2022 and (P < 0.008**) in 2023, while 2024 shows no significant differences (Table 3.1). The Radmira variety has the longest spike length (10.90 cm in 2022 and 9.51cm in 2023). On the other hand, in 2024, the Belyana variety surpasses Agros and Radmira with a spike length of 9.05 cm; however, when we analyzed the three-year average, the Radmira variety (9.81cm) has distinctly longer spikes compared to the two new varieties. The study shows that Radmira displayed relatively uniform spike lengths across all three years. However, Belyana showed a high performance in 2024 (9.05 cm) with a slightly higher mean impact than Agros (8.98cm). It was worth noting that both varieties exhibited a reduction of (± 7.44 cm for Agros and 6.01cm for Belyana) over the standard variety Radmira. These statistically significant variations between varieties, particularly in 2022 and 2024, can be attributed to genetic and environmental factors.

In analyzing cultivation technology, the most extended spike length (10.87cm) was observed under highly intensive technology, outperforming the basic (9.63cm) and intensive (10.77cm) approaches in 2022, and a similar trend was observed in 2023 (Table 3.1). Nonetheless, in 2024, intensive technology (9.13cm) exhibited better performance compared to high-intensive and basic technology. In comparing the annual averages over the three years, it was observed that the intensive technology shows the longest spike length of 9.62 cm, compared to the basic and high-intensive technologies. When we compare the increase over the control, it reveals a percentage increase of 7.84 cm with the intensive system. The findings demonstrated that Intensive technology and Radmira are potential varieties for achieving longer spike lengths, as this trait is a crucial factor influencing wheat yield. Intensive technology enhances spike length, which indicates its viability in terms of growth trait development. The decline in spike length from 2022 to 2024 highlights environmental fluctuations, which may be attributed to drought, temperature variations, or nutrient depletion. Research indicates that spike length is a crucial factor influencing wheat productivity, as it correlates with grain production and biomass accumulation [253, 254]. Technological advancements, including balanced fertilization and crop protection techniques, have improved spike length and grain yield [255]. The fluctuation in spike length attributable to climatic factors corresponds with worldwide observations on wheat output, highlighting the influence of climate on wheat production [256]. Our results highlight the importance of cultivar selection and technological approaches in increasing spike length in spring wheat. Although Radmira, coupled with Intensive technology, demonstrated encouraging outcomes, environmental instability is a critical element influencing wheat output. Consequently, farmers and breeders should employ advanced technologies to enhance productivity while minimizing unnecessary input costs. Nonetheless, Future research should focus on improving genetic resilience varieties and optimizing agronomic approaches to guarantee consistent and elevated yield traits across diverse environmental circumstances.

3.1.3. Interactive effect of varieties and cultivation technologies on plant height of spring wheat varieties.

Having determined the main effects of variety and technology on spring wheat growth parameters, i.e., plant height and spike length, it was also necessary to assess the interaction effects between these factors. Therefore, the interaction effects of varieties and cultivation technologies on wheat growth traits were evaluated, and the results are presented (Table 3. 2).

Analysis of the pooled data revealed that variety and cultivation technology interacted significantly ($P < 0.001$) in 2022 and 2023, affecting wheat plant height. The interaction of

Agros with all three cultivation technologies was the strongest and most effective, as this variety achieved the tallest plant height, ranging from 96.3 cm under intensive technology in 2022 to 128.1cm with high-intensive technology in 2023 and 135.3 cm with intensive technology in 2024. Conversely, Belyana was the least responsive to cultivation technologies, exhibiting the shortest plant height for both basic and high-intensive technologies. The heights ranged from 68.7 cm with the basic system in 2022 to 107.3 cm under intensive technology in 2023 and 127.3 cm in 2024. Under intensive technology, the Radmira variety responded steadily, with plant heights of 87.1 cm in 2022, 120.3 cm in 2023, and 136.4 cm in 2024, respectively. Across the three-year average, the Agros variety attained the highest plant height (118.8cm) under intensive technology, followed by Radmira (114.6 cm) and Belyana (99.9 cm), which had the lowest average plant height (Table 3,2). Recent studies by [16, 17, 18] indicate that *T. aestivum* has exhibited poor performance in most wheat-producing regions, primarily due to the detrimental impact of dry autumn weather, poor management practices, and disease incidence. Therefore, our results attained in this study recommend the timely application of fertilization and disease management practices in early spring to accelerate regeneration processes, thereby promoting optimal growth and development, which are crucial.

Table 3.2 – Interactive effect of varieties and cultivation technologies on Plant height and Length of spikes per plant of spring wheat

	Plant height (cm)				Length of spikes^{-1} (cm)			
	2022	**2023**	**2024**	**Three years Average**	**2022**	**2023**	**2024**	**Three years Average**
Treatment interactions								
Agros× Basic	89.6	124.5	129.2	114.4	8.7	8.2	8.8	8.6
Agro×1ntensive	96.3	124.7	135.3	118.8	10.7	8.6	9.1	9.5
Agros× H. Intensive	91.7	128.1	129.5	116.4	10.6	8.0	9	9.2
Belyana× Basic	68.7	106	124.9	99.9	9.7	7.6	9.2	8.8
Belyana×1ntensive	87.8	102.5	127.3	105.9	11.1	8.2	9.0	9.4

Belyana× H. Intensive	82.1	107.3	126.3	105.2	10.3	9.0	9.0	9.4
Radmira× Basic	75.7	106.2	131.4	104.4	10.5	8.5	9.0	9.3
Radmira×1ntensive	87.1	120.3	136.4	114.6	10.5	10	9.3	9.9
Radmira× H. Intensive	85.3	117.4	129.8	110.8	11.7	10.0	8.7	10.1
P-value	<.001***	<.001***	0.105ns	-	0.027*	0.218ns	0.661ns	
LSD 5%	1.19	4.13	2.8	-	0.63	1.09	0.59	
Standard error (AxB)	1.02	1.49	2.11	-	0.50	0.71	0.48	
CV%	1.2	1.3	1.6	-	4.8	8.2	5.3	

CV%= coefficients of variation, LSD 5% = Least significant difference, while Student- test was used to separate the mean, * =significant, ** = very significant, *** =highly significant, ns =not significant.

This study agrees with [17, 18], suggesting that the Intensive and High technology used in this study effectively interacted with all three varieties, as they reached their maximum heights of 135.3 cm (Agros), 136.4 cm (Radmira), and 127.3 cm (Belyana). In contrast, high-intensive technology exhibited weaker interaction with all three varieties over the three years, as evidenced by shorter plants compared to those grown under intensive technology. The most significant height reduction was observed with the basic technologies across all varieties. The study confirms that the intensive techniques developed in this study are a versatile tool that could be applied to all wheat cultivation to increase wheat productivity traits.

3.1.4. Interactive effect of varieties and cultivation technologies on spike length

The interaction between cultivation technologies and varieties significantly influenced the spike length of wheat (P < 0.027) in 2022. In contrast, statistically significant differences were observed in 2023 and 2024 (Table 3.2). The Radmira variety interacted better with all three cultivation technologies than Belyana and Agros, as evidenced by the most prolonged spikes, ranging from 8.5 cm with basic technology in 2022 to 11.7 cm with high-intensive technology in 2022 and 9.3 cm with the intensive approach in 2024. Conversely, in 2023, the Belyana variety also achieved a better spike length in 2022, when cultivated with intensive (11.1cm) and in 2023 (9.0 cm) with high-intensive technology. Moving forward, in 2024, all varieties unveiled statistically similar spike lengths. Spike length is an essential trait primarily controlled by the genetic genome of wheat varieties; as such, genetic factors, environmental uniformity, and nutrient use efficiency might have influenced the similarities and variations of this trait. The ANOVA analysis for the three-year average reveals that Radmira obtained the longest spikes (10.1 cm) under the high-intensity system, followed by Agros (9.5 cm) under the intensive system (Table 3.2). These significant increases might be related to the effective cultivation technologies formulated coupled with the varieties selected in this study Our research findings agree with those of [20, 21, 22, 23, 24], demonstrating that applying urea, ammonium nitrate, or ammonium sulfate during crucial stages of wheat development enhances spike length and increases the number of grains during the grain filling stage, which boosts grain yield. The application of nutrients and crop protection techniques in this study enables better wheat performance, particularly in the face of significant climatic variations and various biotic and abiotic factors, which are key determinants of our findings. This research demonstrated that farmers can utilize intensive and high-intensity production technologies with Belyana and Radmira varieties to achieve better wheat production output.

3.1.5. The influence of varieties and cultivation technologies on the number of spikelets per spike

Regarding the number of spikelets per spike, the analysis of variance revealed no significant statistical differences ($P > 0.05$), indicating that there was no varietal effect on this trait over the three years. Notwithstanding, the finding observed minor variances among the three varieties, with the Agros variety achieving the highest number of spikelets per spike (16.40) in 2022, whilst Radmira ranked first in 2023 (16.77) and Belyana led (13.91) in 2024. However, considering the highest values for the three growing years, the Belyana variety (15.29) achieved the highest number of spikelets per spike, with a corresponding percentage increase over control of (± 1.84%) (Table 3.3).

Although there was no varietal effect on the number of spikelets per spike, cultivation technologies significantly influenced this trait in 2022 ($P < 0.001$); however, no statistical significance was observed in 2023 and 2024. The highest spikelets per spike (17.07) were obtained 2022 17.07 in 2022 under intensive technology. In 2024, intensive and high-intensive technologies were statistically comparable, attaining the same number of spikelets per spike (13.19). Basic technology had the fewest spikelets per spike in all three years, significantly differing from intensive and high-intensive technologies (Table 3.3). When the data was analyzed for the three years average it unraveled that intensive technology exhibited the highest number of spikelets per spike (15.61), making a percentage increase of (± 7.60%) over control plots (basic technology) Table 3.3.

The research findings indicate that the varietal effect did not influence the number of spikelets per spike. However, when the number of spikelets per spike was assessed using cultivation technology as a variable, the result obtained was significant compared to basic technology. The average value for technologies indicates that the trait responds to intensive and high-intensive cultivation technologies, suggesting that it is externally controlled by factors such as agricultural practices and the environment.

These results agree with [257, 258], which state that using different treatment combinations yielded the highest number of spikelets per spike in all treatment combinations compared to all control plots. Each spikelet contains many grains; the better the number of spikelets per spike and the number of grains per spikelet, the higher the number of wheat grains per spike, hence a high grain yield [259].

This trait is crucial for high yield and can also be used for wheat breeding improvement. Our results revealed that intensive cultivation technology and the Belyana variety achieved the highest number of spikelets per spike over the three years, indicating that they could be an ideal agricultural practice for increasing the number of wheat spikelets per spike.

Table 3.3 – Influence of three varieties and three cultivation technologies on the number of spikelets per spike and the number of seeds per spike of spring wheat

Treatments	**Number of spikelets spike^{-1}**			**Three years Average**	**± Basic (%)**	**Number of seeds spike^{-1}**			**Three years Average**	**± Basic %**
	2022	**2023**	**2024**			**2022**	**2023**	**2024**		
Main Plot: Cultivation Technology										
Basic	14.67	15.72	13.14	14.51	-	31.93	35.79	31.73	33.15	-
Intensive	17.07	16.58	13.19	15.61	7.60	38.83	37.82	33.24	36.63	10.50
High -intensive	16.57	15.78	13.19	15.18	4.62	38.00	40.06	32.62	36.89	11.29
P-value	<.001***	0.334^{ns}	0.965^{ns}	-	-	<.001***	0.041*	0.774^{ns}	-	-
LSD 5%	0.49	1.56	0.58	-	-	0.31	3.57	2.46	-	-
Standard error (A)	0.22	0.69	0.26	-	-	0.14	1.58	1.08	-	-
CV%	1.4	4.3	1.9	-	-	0.4	4.2	3.3	-	-
Sub plot: Varieties										
Agros	16.40	15.42	13.17	15.00	-0.11	37.77	33.80	33.04	34.87	-6.86
Belyana	16.07	15.89	13.91	15.29	1.84	33.20	37.19	33.73	34.71	-7.29
Radmira (Standard)	15.83	16.77	12.44	15.01	-	37.80	42.68	31.83	37.44	-
P-value	0.080^{ns}	0.043^{ns}	0.009*	-	-	<.001***	<.001***	0.086^{ns}	-	-
LSD $_{5\%}$	0.49	0.97	0.65	-	-	0.42	1.86	1.72	-	-
Standard error (B)	0.22	0.43	0.29			0.18	0.82	0.76		
CV%	1.4	2.7	2.2	-	-	0.5	2.2	2.3	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, *** =highly significant, ** = very significant, * =significant, ns =not significant.

3.1.6. The influence of varieties and cultivation technologies on the number of seeds per spike

ANOVA result presented in Table (3.3) showed that the number of seeds spike^{-1} evaluated in 2022 and 2023 revealed significant differences ($P < 0.05$) in 2022 and 2023 years. In contrast, in 2024, there were no significant differences ($P>0.05$). ANOVA exhibits that the Radmira variety had the highest number of seeds spike^{-1} (37.80) in 2022 and (42.68) in 2023, followed by the Agros variety (37.77) in 2022, while the Belyana variety showed the least (33.20) in the same year. The Belyana variety (37.19) shows the second-highest number of seeds per spike in 2023. In 2024, there were no significant differences among the varieties; however, Belyana (33.73) had the highest number of seeds spike^{-1}. The final average across the three growing seasons shows that Radmira achieved the highest seeds per spike (37.44), followed by Agros (34.87) and Belyana (34.71). However, when compared to the standard variety Radmira, the Belyana (±7.29) and Agros (±6.86) varieties showed a decrease in the number of seeds per spike. The findings over the three years showed that the Radmira variety had the highest number of seeds per spike (37.44). This could be related to the genetic makeup of the variety's genome.

In 2022, the High Intensive and Intensive technologies showed similar statistical numbers of seeds spike-1 (38.83) for Intensive and high-intensive (38.00), which shows no statistical differences, while the basic technology had the fewest seeds spike^{-1} (31.93). In 2023, high-intensive technology attained the highest number of seed spikes (40.06). However, in 2024, intensive (33.24) and high-intensive (32.62) technologies unraveled a slight variance in this trait, which shows no statistical variation (Table 3. 4). The mean values for the three cultivation seasons demonstrated that both intensive and High-intensive and Intensive technologies had similar increases, hence both increases by (10.50% intensive and 11.29% High Intensive compared to Basic. These technologies demonstrated that they could be employed to increase the number of seeds per spike.

Our findings suggest that intensive and high-intensity technologies, combined with Radmira varieties, could be recommended for achieving high yields in wheat production, thereby meeting the world's demand for wheat. Our result is consistent with studies conducted by various researchers, which indicate that growth traits play a pivotal role in achieving high wheat yields under an integrated management system [260, 261, 262, 263, 264]. Seeds per spike and other yield traits in wheat cultivation speak volumes about high yield per hectare in any production system. Varieties and cultivation technology in our study had a significant impact on these traits, with the Radmira variety obtaining the maximum average number of seeds spike^{-1}, followed by the Agros variety under intensive and high-intensive technologies (Table 3.3). The findings suggest that continued research on these cultivation technologies in other regions of Russia, including different varieties, can salvage the high demand for wheat by 2050.

3.1.7. Interactive effect of varieties and cultivation technologies on the number of spikelets per plant

The interactive effect of three varieties and three cultivation technologies on the number of spikelets per spike was assessed. It was observed that the interactive effect of variety and cultivation technology had a significant impact on the number of spikelets per spike-1 obtained ($P < 0.05$) in 2022 (Table 3.4); however, no significant effect was observed in the 2023 and 2024 growing seasons. At the intensive and high-intensive production levels, all three varieties were better adapted to this approach, as highlighted by the highest number of spikelets per Spike. In 2022, the Agros variety had the highest number of spikelets per spike (17.7) under high-intensity technology, while in 2023, Radmira exhibited the highest number of spikelets per spike (17.3) with intensive technology. In 2024, although no statistically significant levels were observed, the Belyana variety had the highest number of spikelets per spike (13.95) when cultivated under an intensive technology system. The average output for all three years demonstrated that Radmira variety (15.95) with intensive management attained the highest number of spikelets, followed by Belyana (15.78) with the same intensive practices. It was worth noting that all three varieties responded differently over the years. The varying interactions of wheat types towards intensive and high-intensive production regimes, even when produced under the same weather conditions, could be attributed to variations in their genetic composition, nutrient use efficiency, and physiological characteristics.

However, with a steady increase in production intensity at each level, all three varieties exhibited high interaction, recording the highest number of spikelets per spike in the intensive experimental trials.

Table 3.4 – Interactive effect of three varieties and three cultivation technologies on the number of spikelets per spike and the number of seeds per spike of spring wheat.

Parameters	**Number of spikelets spike $^{-1}$**				**Number of seeds spike^{-1}**			
	2022	**2023**	**2024**	**Three years Average**	**2022**	**2023**	**2024**	**Three years Average**
Treatment interactions								
Agros× Basic	14.4	14.4	13.13	13.98	30.3	32.6	32.2	31.70
Agro×Intensive	17.1	16.5	13.07	15.56	40.4	34.4	33.7	36.17
Agros× H. Intensive	17.7	15.4	13.32	15.47	42.6	34.4	33.2	36.73
Belyana× Basic	15.1	15.7	12.57	14.46	30.9	33.5	34.0	32.80
Belyana×Intensive	17.4	16.0	13.95	15.78	36.9	35.2	33.2	35.10
Belyana× H. Intensive	15.7	16.0	13.93	15.21	31.8	42.9	34.1	36.27
Radmira× Basic	14.5	16.1	12.35	14.32	34.6	41.3	32.0	35.97
Radmira×Intensive	16.7	17.3	13.84	15.95	39.2	43.9	32.9	38.67
Radmira× H. Intensive	16.3	17.0	12.41	15.24	39.6	42.8	30.6	37.67
P-value	0.037*	0.471^{ns}	0.984^{ns}	-	<.001***	0.037*	0.769^{ns}	-
LSD 5%	0.81	1.84	1.00	-	0.89	5.85	3.39	-
Standard error (AxB)	0.61	1.15	0.74	-	0.77	4.85	2.48	-
CV%	3.8	7.2	5.6	-	2.1	12.8	7.5	-

CV%= coefficients of variation, LSD $_{5\%}$ = Least significant difference, while Student- test was used to separate the means, * =significant, ** = very significant, *** =highly significant, ns =not significant

Research by various scholars has demonstrated that applying mineral fertilizers, crop protection agents, and best agronomic practices significantly enhances wheat growth parameters, including the number of spikelets per spike, seeds per spike, seed weight, and overall yield. These improvements are attributed to better nutrient use efficiency when applied at optimal amounts and at the appropriate periods within wheat production systems [254, 265, 266, 260]. Furthermore, studies have shown that different wheat cultivars exhibit considerable variation in their performance under diverse agronomic practices [254]. These findings align with our results, which indicate that the selection of Radmira and Belyana varieties under intensive cultivation technologies not only enhances these growth traits but also maximizes yield. This demonstrates an apparent, interactive effect between the choice of cultivars and the application of intensive agronomic techniques in the study.

Overall, these varieties showed high responsiveness; alternatively, the intensive cultivation technology proved to be the most optimal across all three spring varieties. This is logical, considering that intensive technology has a higher input investment, which is optimal for wheat development and productivity. The high-intensity technology was affected in all three years; it was observed that there were low diminishing returns, hence the lower output compared to the intensive production method across the varieties (Table 3.4).

3.1.8. Interactive effect of varieties and cultivation technologies on the number of seeds per spike

The differences in the number of seeds per spike were determined among the studied cultivars. The analysis of variance revealed a significant interaction effect between the two factors, variety and cultivation technology ($P<.001$) for 2022 and 2023, Table 3.4. The highest number of seed spikes (1, 42.6) was obtained when the variety Agros was produced under high-intensity technology in 2022. However, it must be noted that the same variety (Agros) had the lowest seed yield (30.3) per spike when produced under basic technology, revealing the high sensitivity of the variety to high input investment. When the input investment is high, the variety responds favorably, producing high-yield traits, and vice versa. When the input investment is relatively low, as exhibited in the basic technology approach, the variety underperforms. This can be attributed to the genetic variability of the variety Agros. In 2023, the Radmira variety exhibited the highest number of seeds per spike (43.9) when produced under intensive technology, followed by Belyana (42.9) when produced under high-intensive technology. It was observed that in 2024, both Belyana (34.1) under high-intensive technology and Agros (33.7) under intensive were statistically similar in attaining the number of seeds spike^{-1}. Analysis of ANOVA reveals that the three-year average shows the Radmira variety achieved the highest number of seeds per spike (38.67) under the intensive system, followed by Agros (36.73) under the high-intensive system. The result illustrated that when the inputs were increased in the high-intensive approach, the number of seeds per spike decreased significantly, as manifested with Agros and Radmira in comparison with the intensive technology treatments. Table (3.4). It can therefore be noted that intensive and high-intensity technologies are the optimal practices for producing high wheat seeds per spike, depending on the cultivar selected. Additionally, our findings revealed phenotypic variance, suggesting a significant influence of environmental factors on the expression of this trait. These findings agree with [267, 260], who noted that productive characteristics, such as the number of seeds per spike, varied within the same cultivars and between different cultivars in different years of investigation, as established in their study.

The intensive and high-intensive technologies had statistically comparable interaction effects on the Radmira variety in terms of obtaining the highest average number of seeds per spike. It was interesting to observe that when resources were limited in basic technology, the Radmira variety also attained the highest productivity (34.6 and 41.3 in 2022 and 2023, respectively) and Belyana (34.0 in 2024), as indicated by the number of seeds per spike (Table 3.4).

Therefore, to enhance yield and its components, augmenting the impact of genetic factors on all yield-related attributes, Breeders need to initiate the enhancement of gene control to increase the capacity of these qualities, as well as the morpho-anatomical structure and physiological function, which will subsequently elevate the value of yield components.

3.1.9. The influence of varieties and cultivation technologies on the weight of seed spike^{-1} (g)

In determining the weight of seed per spike, the analysis of variance in 2022 revealed that the Agros variety attained heavier seed spikes (1.93g) than both Radmira (1.67g) and Belyana (1.63g), which are statistically similar. In comparison, the 2023 cropping calendar showed that the Radmira (1.55g) variety achieved the heaviest seeds per spike, while Agros (1.50g) and Belyana (1.50g) attained the least, with the exact weight of seeds per spike. In 2024, Agros (1.39g) again exhibited denser seed weight over both varieties. Significant heterogeneity was observed among the growth characteristics of the tested cultivars for varietal comparison. However, the three-year values show that the Agros variety (1.61g) obtained denser seed weight per spike, followed by Belyana (1.49g), and Radmira the least (1.46g), although they were statistically comparable regarding this trait. In evaluating for percentage increase, the Agros variety increased by (10.30%), while Belyana increased by (2.06%) over the standard Radmira. These year variations could be linked to the genetic makeup of the varieties, as well as the cultivation technologies used in the study, seasonal and environmental effects. Research by [266, 260] discovered that several wheat cultivars exhibit significant variability in their seed weight traits when subjected to different agronomic practices, seasonal differences, and environmental impact (Table 3.5).

Regarding cultivation technology performance, the intensive (1.90g) and high-intensive (1.90g) technologies have similar influences on seed weight per spike in 2022. In 2023, high-intensive technology (1.63g) took the lead; however, in 2024, intensive technology (1.33g) surpassed both technologies. In contrast, the Basic technique had the least seed weight per spike for all three years. In assessing the three years, high-intensive technology (1.60g) performed better, but was statistically comparable with intensive technology. However, the percentage increase proved that High-Intensity technology obtained a denser seed weight of 15.42% compared to Intensive (13.25%) and Basic technology. Our findings demonstrate that High-intensive cultivation techniques used in the study could be adopted to produce denser seed weight, hence, improve wheat production

(Table 3.5). Our findings concur with [268, 269], which state that integrated nutrient management for growth, yield, and yield attributes can increase wheat production and aid measures to stabilize the global wheat supply and enhance food security.

3.1.10. The influence of varietal and cultivation techniques on 1000 grain weight (g)

In assessing the trait of 1000-grain weight of the studied varieties, significant variability ($P < 0.05$) was observed. The Agros variety (45.80g) had the highest 1000-grain weight, followed by Belyana (41.23g) in 2022. However, Belyana was not statistically different from Radmira (40.63g), with the lowest 1000-grain weight in 2022. A similar trend occurred in 2023, where the Agros variety also had the highest 1000-grain weight (39.03g), followed by Radmira (36.21g) and Belyana (36.16g)1000-grain weight with no statistical difference. In the 2024 cropping season, the Agros variety (36.53g) also achieved the highest 1000-grain weight, and Belyana (36.06g) was the second highest, compared to Radmira (32.28g). Over the three years, it was evident that the Agros variety attained the highest 1000-grain weight (40.45g) with a percentage increase of 11.22% over Belyana and Radmira. Overall, our findings show that Agros achieved a healthier 1000-grain weight; hence, denser grains were obtained. This can be attributed to their genotypic traits, effective nutrient use efficiency, crop protection chemicals utilized in this study, and appropriate fertilizer management. The results align with those of [263, 262, 265], which suggest that improved nutrient management, including the use of hybrid wheat varieties, enables producers to produce healthier and denser seeds, ultimately achieving higher yields to meet global demand (Table 3.5). Our findings suggest that the utilization of appropriate resources greatly impacted the growth and yield traits of spring wheat Agros and Belyana varieties.

Table 3.5 – Influence of three varieties and three cultivation technologies on the weight of seeds per spike and the Mass of 1000 grain weight of spring wheat

Treatments	Weight of seeds spike^{-1}			**Three years Average**	**± Basic (%)**	Mass of 1000 grains weight			**Three years Average**	**± Basic %**
	2022	**2023**	**2024**			**2022**	**2023**	**2024**		
Factor A: Cultivation Technology										
Basic	1.43	1.44	1.28	1.38	-	39.80	35.51	33.04	36.12	-
Intensive	1.90	1.47	1.33	1.57	13.25	42.00	37.28	35.30	38.19	5.75
High - Intensive	1.90	1.63	1.26	1.60	15.42	45.87	38.60	36.43	40.30	11.58
P-value	0.65^{ns}	0.046*	0.431^{ns}	-	-	<.001***	<.001***	<.001***	-	-
LSD 5%	0.00	0.15	0.13	-	-	0.40	0.70	0.42	-	-
Standard error (A)	0.00	0.07	0.06	-	-	0.18	0.31	0.18	-	-
CV%	0.0	4.5	4.3	-	-	0.4	0.8	0.5	-	-
Factor B: Sub Plot: Varieties										
Agros	1.93	1.50	1.39	1.61	10.30	45.80	39.03	36.53	40.45	11.22
Belyana	1.63	1.50	1.33	1.49	2.06	41.23	36.16	36.06	37.82	3.97
Radmira (Standard)	1.67	1.55	1.15	1.46	-	40.63	36.21	32.28	36.37	-
P-value	0.010**	0.944^{ns}	0.005**	-	-	<.001***	0.045*	<.001***	-	-
LSD $_{5\%}$	0.15	0.44	0.10	-	-	0.39	2.53	0.32	-	-
Standard error (B)	0.07	0.19	0.04			0.17	1.12	0.14		
CV%	1.93	1.50	1.39	-	-	45.80	39.03	36.53	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, *** =highly significant, ** = very significant, * =significant, ns =not significant

Significant variance (P ≤ 0.05) was observed across the three cultivation technologies in terms of 1000-grain weight. High-intensive technology resulted in the highest weight of grains (45.87g) in 2022, (38.60g) in 2023, and (36.43g) in 2024. In contrast, intensive technology had a moderate weight of 42.00g in 2022, 37.28g in 2023, and 35.30g in 2024, while Basic technology had the lowest 1000-grain weight across all three years (Table 3.5). Over the three years, the 1000-grain weight demonstrated that high-intensive technology produced denser grain with a percentage increase of 11.58% compared to intensive (5.75%) and Basic technologies. This can be attributed to the higher quality of nutrients supplied to the crops in this production technique, including the efficient crop protection techniques applied during the growing stages. The varieties produced by this approach had more nutrients channeled towards the seeds. This is in line with findings that the application of appropriate fertilizer rates and better integrated crop protection management improve wheat growth, yield, and quality attributes [29, 265]. Findings indicate that understanding varietal choice, including crop nutrient management and uptake and removal, can help producers better match plant nutritional needs to achieve a target yield goal.

3.1.11. The interactive effect of varieties and cultivation technologies on the weight of seed spike^{-1}

The ANOVA results showed an interaction effect between the two factors on seed weight per spike (P < 0.006) in 2022, while 2023 and 2024 show no statistical significance. The combination of high-intensity production technology and the variety Agros yielded the highest seed weight spike-1 (2.30g) in 2022. Moving forward, the second-highest recorded seed weight per spike (2.10g) was achieved with the same variety (Agros) when produced under intensive technology. It was statistically similar to the high-intensive techniques (Table 3.6). In that same year, 2022, intensive technology had a similar interaction with both Belyana and Radmira varieties, producing the same seed weight spike^{-1} of (1.80g) and (1.80g), respectively. Furthermore, in 2023, the Agros (1.69g) and Belyana (1.69g) varieties were produced under high-intensive technology; both attained similar seed weights, while

Radmira exhibited the least seed weight spike (1.56g and 1.52g) for intensive and high-intensive technologies. In 2024, it was worth noting that the Agros variety had (1.44g) seed weight per spike with intensive technique compared to Belyana (1.35g) and Radmira (1.19g) under intensive system of cultivation (Table 3.6). Looking at the average over the three cultivation seasons, we observed that Agros took the lead in achieving (1.79g)with high-intensive, followed by Belyana(1.57g) with intensive. Our findings have established that cultivation intensity can increase the weight of seed per spike, through both intensive and highly intensive technologies, depending on the variety used (Table 3.6). Similar studies were carried out by [261, 264, 262]; in their research, it was established that using intensive cultivation systems with the hybrid wheat variety Moskovskaya 39 increased the weight of seeds per spike (2.0g).

Table 3.6 – Interactive effect of three varieties and three cultivation technologies (a×b) on the weight of seeds per spike and the Mass of 1000 grain weight of spring wheat

Parameters	**Weight of seeds spike^{-1}(g)**				**Mass of 1000 grain weight (g)**			
	2022	**2023**	**2024**	**Three years Average**	**2022**	**2023**	**2024**	**Three years Average**
Treatment interactions								
Agros× Basic	1.40	1.51	1.35	1.42	43.0	37.1	34.8	38.30
Agro×1ntensive	2.10	1.30	1.44	1.61	44.6	39.4	36.7	40.23
Agros× H. Intensive	2.30	1.69	1.37	1.79	49.8	40.5	38.1	42.80
Belyana× Basic	1.40	1.25	1.33	1.33	40.1	35.3	33.8	36.40
Belyana×1ntensive	1.80	1.55	1.35	1.57	41.1	36.4	37.3	38.27
Belyana× H. Intensive	1.70	1.69	1.30	1.56	42.5	36.8	37.1	38.80
Radmira× Basic	1.50	1.55	1.13	1.39	36.3	34.1	30.5	33.63
Radmira×1ntensive	1.80	1.56	1.19	1.52	45.3	36.0	31.9	37.73
Radmira× H. Intensive	1.70	1.52	1.11	1.44	40.3	38.5	34.4	37.73
P-value	0.006^{**}	0.133^{ns}	0.973^{ns}	-	$<.001^{***}$	0.003^{**}	0.002^{***}	-
LSD 5%	0.21	0.44	0.17	-	0.54	2.49	0.54	-
Standard error (AxB)	0.12	0.18	0.12	-	0.32	0.43	0.36	-

CV%	6.6	12.2	9.5	-	0.8	1.2	1.0	-

CV%= coefficients of variation, LSD 5% = Least significant difference, while Student- test was used to separate the means, * =significant, ** = very significant, *** =highly significant, ns =not significant

The findings reveal that, on average, the Agros variety attained the highest seed weight per spike with high-intensive and intensive cultivation, followed by Belyana and Radmira under intensive technology, indicating a high interactive effect of the varieties and cultivation technology. The basic technology option has no significant influence on this trait (Table 3.6). Our research demonstrates that to achieve a dense seed weight in spring wheat, the Agros and Belyana varieties, combined with intensive and high-intensity production systems, could be a better option for producers and breeders due to their unique characteristics. Several studies suggested that with the proper varietal selection and adequate nutrients and crop protection combination, specific outputs, such as the number of grains per spike, the weight of grains per spike, the mass of 1000 grains, and yield, can be enhanced [253, 262, 29, 261, 264]. This study demonstrates that increasing yields and maximizing returns require the adequate use of intensive and high-intensity production systems, such as those utilizing varieties like Agros and Belyana. The findings established a significant influence of these production systems, and the novel varieties used in this study suggest that producers and breeders could potentially exploit the productivity of spring wheat by utilizing these varieties.

3.1.12. The interactive effect of varieties and cultivation technologies on the 1000-grain weight (g).

Approximately 50% of the rise in wheat yields may be attributed to improved and hybrid varieties, while the other 50% is attributable to improved management practices. Given the uncertain and varied climatic conditions, careful variety selection and integrated nutrient management techniques can significantly influence profitability, ensuring high yields and better wheat quality [252]. In our field experiment, we assessed the interactive effect of varieties and three cultivation technologies. The results show that high-intensity technology applied to the Agros variety produced the highest 1000-grain weight (49.8g), while the Radmira variety was the second highest (45.3g) under intensive technology in 2022. However, with the high-intensive technology, Radmira performed dismally in 2022, as it was observed that the 1000 seed weight declined from 45.3g to 40.3g. This was lower than the 1000-grain weight of Agros (43.0g) produced under basic technology and statistically similar to Belyana (40.1g) under the same conditions. Radmira performed better than Belyana under intensive production technology (45.3g), showing that this variety is adapted to optimum input conditions. It is essential to maintain balance when investing inputs in this variety, as excessive inputs will result in very low 1000-grain weight, and high input investments lead to regression in terms of 1000-grain weight. In 2023, Agros also had the highest 1000-grain weight (40.5g), followed by Radmira (38.5g) and Belyana (36.8g) when produced under a high-intensity production system. The Agros variety also emerged in 2024, achieving the highest 1000-grain weight (38.1g) with high-intensity technology. Belyana subsequently had the second-highest 1000-grain weight (37.1g), and Radmira had the lowest (34.4g), both with high-intensity technology. In comparison, all three varieties interacted significantly (<.001) with high-intensive technology; on average, Agros yielded the most (42.80g), followed by Belyana (38.80 g) and Radmira (37.73g), respectively. Our findings, however, observed a decrease in 1000-grain weight obtained with the variety Radmira in 2022, from 45.3g with intensive technology to 40.3g with high-intensive technology. This could have resulted from excessive nitrogen availability, leading to reduced plant growth at the expense of the reproductive phase. Hence, this yield component performs poorly (Table 3.6). These results can be attributed to genetic variations; for example, each variety has unique traits that determine its ability to utilize resources. Additionally, varieties with higher genetic yield potential tend to perform better under a high-production system because they can exploit the increased availability of resources. Findings from several researchers [268, 269, 265, 262] suggest that the use of hybrid varieties in conjunction with suitable production systems can improve the growth traits of wheat varieties. Our findings demonstrated that the Agros and Belyana varieties could be the best hybrid for wheat productivity when cultivated under high-intensive production systems. At the same time, Radmira can perform better even with fewer inputs, such as intensive technology. As indicated earlier, hybrid varieties are responsible for around 50% of the increase in wheat yields, with enhanced management techniques accounting for the other 50%; hence, these cultivation technologies (intensive and high-intensive) technologies with Agros and Belyana varieties are key players in achieving global wheat demand.

3.2. Grain Yield Analysis

3.2.1. The impact of wheat varieties and cultivation technologies on yield (t/ha)

The yield data analysis from 2022 to 2024 revealed significant differences among the three spring wheat varieties ($P < 0.05$), as shown in Table 3.7. Belyana demonstrated the highest average yield (4.84 t ha^{-1}), followed by Agros (4.78 t ha^{-1}), and Radmira had the lowest yield (3.89 t ha^{-1}) in 2022. In 2023, Radmira (5.07 t.ha^{-1}) superseded Belyana (4.42 t.ha-1) and Agros (3.80 t.ha-1), respectively. Moving forward, in 2024, Agros variety exhibited a sharp increase (4.95 t ha^{-1}), outperforming Belyana (4.66 t ha^{-1}) and Radmira (4.37 t ha^{-1}). Although there were variations in yield performance across all three years, Belyana (4.64 t ha^{-1}), attaining the highest average grain yield consistently, showed stable production throughout the three years, with an increase in percentage yield of 4.42% compared to Agros (1.50%) and Radmira, the standard variety. The statistical significance ($P < 0.05$) in yearly variations indicates that environmental factors, cultivation technologies, and varietal adaptability played a crucial role in yield performance.

These findings suggest that genetic potential alone does not explain yield variability over multiple years; instead, an adequate integrated management approach, combined with environmental conditions, biotic factors, and agronomic management, is equally significant. These findings align with studies by [270, 271, 268, 259], who reported that wheat yield fluctuations among varieties are often linked to better integrated management, environmental adaptability, nutrient uptake efficiency, and varietal resistance to abiotic and biotic stress factors, such as drought and extreme temperatures, as well as disease incidence.

The analysis of variance revealed a significant impact ($P < 0.001$) on yield due to the different cultivation technologies applied. High-intensity technology consistently produced the highest yields (5.01 t ha^{-1}) in 2022, (4.78 t ha-1) in 2023, and (4.94 t ha-1) in 2024, respectively. The intensive system also revealed a maximum yield that is encouraging as compared to the Basic cultivation system (Table 3.7). The average percentage increase that was recorded for High Intensive was (23.16%), and Intensive was (17.73%) in terms of yield compared to basic cultivation technology (Table 3.3).

Table 3.7– Influence of three varieties and three cultivation technologies on the yield of spring wheat

Treatments	**Yield t ha^{-1}**			**Three years Average**	**± Basic (%)**
	2022	**2023**	**2024**		
Factor A: Cultivation Technology					
Basic	3.64	4.05	4.27	3.99	-
Intensive	4.86	4.46	4.76	4.69	17.73
High -intensive	5.01	4.78	4.94	4.91	23.16
P-value	<.001***	<.001***	<.001***	-	-
LSD 5%	0.14	0.14	0.08	-	-
Standard error (A)	0.06	0.06	0.04	-	-
CV%	1.4	1.4	0.8	-	-
Factor B: Varieties					
Agros	4.78	3.80	4.95	4.51	1.50
Belyana	4.84	4.42	4.66	4.64	4.43
Radmira	3.89	5.07	4.37	4.44	-
P-value	0.007**	<.001***	<.001***	-	-
LSD 5%	0.22	0.17	0.01	-	-
Standard error (B)	0.10	0.08	0.01	-	-
CV%	2.2	1.7	1.0	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, *** =highly significant, ** = very significant, * =significant, ns =not significant.

Across all years, the high-intensive system outperformed intensive and basic approaches, confirming that optimized agronomic inputs, including proper fertilization, advanced crop protection techniques, and improved soil management, enhance yield potential. Our results demonstrate high nutrient availability to wheat crops and the effectiveness of appropriate plant protection treatments. Our research findings align with those of [272, 273; 274, 251, 29], who reported that wheat responds positively to higher-input cultivation systems due to improved nutrient availability, appropriate fertilization techniques, reduced resource competition, and enhanced stress tolerance to most biotic and abiotic stressors. Other researchers established that [251, 29, 271] attaining high wheat yields involves the application of appropriate mineral fertilizers, growth regulators, and crop protection products. The yield performance across the three years (2022–2024) showed statistically significant results, confirming that environmental conditions and appropriate cultivation techniques, including crop protection measures, significantly influenced productivity. The slight reduction in the 2023 wheat yield is likely due to disease incidence and adverse meteorological factors, including drought stress, temperature fluctuations, and irregular precipitation patterns. These findings align with research by [275, 273], which demonstrates that climate variability and disease prevalence remain critical determinants of global wheat yield instability. The study highlights the importance of varietal selection in wheat cultivation. Belyana consistently outperformed other varieties in terms of steady yield, indicating its potential as a preferred cultivar for stable yields under diverse agroecological conditions. Therefore, future breeding programs should aim to improve wheat genotypes that are resilient to diverse agroecological conditions and exhibit high nutrient-use efficiency, thereby enhancing wheat yield and meeting the increasing global demand for this crop. The high-intensity cultivation system significantly increased yields, confirming the importance of advanced agronomic practices in maximizing productivity and profitability. This study demonstrated that varietal selection, agronomic management, and climate variability are crucial factors influencing spring wheat yield performance. The findings emphasize the necessity for region-specific, adaptive cultivation strategies to optimize yields under field conditions (Table 3.7).

3.2.2. Interactive effect of three spring wheat varieties and three cultivation technologies on yield (t ha^{-1})

The statistical analysis of the pooled data for yield traits revealed significant interaction effects among the three varieties and the three cultivation technologies ($P < 0.05$), as shown in Table 3.8. The interactive effects of three spring wheat yield under three different cultivation technologies were evaluated across three spring cultivation seasons (2022, 2023, and 2024). The analysis of variance reveals a significant interactive effect, indicating that wheat varieties and cultivation technologies have a strong influence on yield output. The variety Agros × high-intensive in 2022 recorded the highest yield of 5. 40 t. ha^{-1} in 2022, followed by Belyana × high-intensive 5.31 t ha^{-1} ` and the lowest yield was recorded with Radmira × basic 2.96 t. ha^{-1} in the same year. Our findings observed that in 2022, yields were high under high-intensive cultivation technologies. In 2023, the Radmira variety obtained the highest yield of 5.30 t. ha^{-1} under an intensive production technique, and Belyana attained second place in yield, achieving 4.70 t. ha^{-1} and Agros have the lowest yield of 4.30 t. ha^{-1} under an intensive system. However, in 2024, the Agros variety attained the highest yield of 5. 22 t. ha^{-1}, under high-intensive technology, and Belyana took second place with a yield of 5.13 t. ha^{-1} with high-intensive, and Radmira had the least. The average result indicates that, over the three years, the Belyana variety attained the highest yields (4.95 t ha-1) with high-intensity technology, followed by Agros (4.84 t ha-1), while Radmira yielded the least (4.75 t ha^{-1}) with intensive technology. According to [25, 250, 276], they demonstrated that high-input cultivation systems improved grain filling, grain yield, spikelet development, and kernel weight. Their findings align with our observed yield increase under high-intensity and intensive technologies.

Our results suggest that improved fertilization, seed treatments, crop protection techniques, and best agronomic practices enhanced wheat productivity. Regarding varietal output, our findings indicate that the Agros, Belyana, and Radmira varieties responded more favorably to intensive production systems, exhibiting higher adaptability to advanced agronomic inputs. The differential yield response among wheat varieties suggests genetic variation in nutrient uptake; our findings are in analogy with [260]. Results also indicate that in 2023 and 2024, there was a steady increase in yield, which may be due to better climatic conditions, the use of appropriate techniques, and improved agronomic practices (Table 3.8). The result of our research proves a positive response to yield output with the varieties' intensity technology; hence, our results are consistent with the findings [250, 276, 277] who reported that an increase in agronomic input (fertilization, seed treatments, and the right crop protection products) significantly enhances wheat yields.

Table 3.8 – Interactive effect of three varieties and three cultivation technologies on the yield of spring wheat

Parameters	Yield t ha^{-1}			
	2022	**2023**	**2024**	**Three years Average**
Treatment interactions				
Agros× Basic	4.01	3.20	4.59	3.93
Agros× Intensive	4.92	4.30	5.03	4.75
Agros× H. Intensive	5.40	3.90	5.22	4.84
Belyana× Basic	3.96	4.10	4.15	4.07
Belyana× Intensive	5.26	4.70	4.69	4.88
Belyana× H. Intensive	5.31	4.40	5.13	4.95
Radmira× Basic	2.96	4.80	4.08	3.95
Radmira× Intensive	4.39	5.30	4.57	4.75
Radmira× H. Intensive	4.31	5.1	4.46	4.62
P-value	0.027*	<.001***	<.001***	-
LSD 5%	0.31	0.18	0.08	-
Standard error (AxB)	0.23	0.04	0.05	-
CV%	5.0	1.0	1.0	-

CV%= coefficients of variation, LSD $_{5\%}$ = Least significant difference, while Student- test was used to separate the means, * =significant, ** = very significant, *** =highly significant, ns =not significant.

High-intensity and intensive technologies had statistically comparable effects across all three varieties, although they were significantly different from basic technology. Furthermore, it is worth noting that basic technology continually produced the lowest yields across all three varieties, with Radmira (a2) exhibiting the lowest yield (2.96 t ha^{-1}) in 2022 (Table 3.8). Therefore, it can be noted that any increase in inputs beyond the intensive level did not significantly impact Radmira wheat yield, indicating that intensive cultivation technology is as effective as high-intensive cultivation in terms of wheat yield. The obtained results agree with research conducted by [277, 278], which revealed that applying high nitrogen (ranging from 120 to 180 Kg ha^{-1}) fully maximizes the potential for wheat production when combined with appropriate sowing densities. Cultivation practices employing a nitrogen-rich fertilizer at an application rate of (N4-180 kg. ha^{-1}) and sowing density of (D4-386 seed m^{-2}) yielded 8448.67 kg. ha^{-1} of wheat [276]. The research demonstrated that high-intensive technology and the Belyana variety significantly enhance yield. However, cost-benefit analysis should focus on determining the economic feasibility for farmers and policymakers in agricultural production systems. Additionally, government and agricultural institutions should promote integrated wheat farming systems that strike a balance between productivity, economic sustainability, and environmental sustainability.

3.3. Quality Traits

3.3.1. The influence of wheat varieties and cultivation technologies on the gluten content (%)

The research results in Table 3.9 represent the assessment of spring wheat varieties and cultivation technologies on the percentage increase of quality traits (Gluten and protein %) over three years of field cultivation and laboratory observations (2022-2024). The three varieties exhibited statistical significance in gluten content and protein content (<.001). The Radmira variety showed the highest gluten content throughout all years, ranging from 27.33% in 2022, 27.11% in 2023, and 21.00% in 2024. Belyana also had the second-highest gluten content of (23.43 % in 2022 and 2023) and a decrease in 2024 to (20.20%). The Agros variety consistently yielded the lowest gluten percentage across all three years. However, the outputs were statistically similar in 2022 (20.27%), 2023 (20.26%), and 2024 (20.77%). On average, the Radmira variety achieved the highest gluten percentage (25.15%), followed by Belyana (22.35%) and Agros (20.43%). The gluten percentage shows a reduction of (± 18.74 for Agros), (± 11.11 for Belyana) compared to the Radmira standard.

According to research, the Agros variety could be an ideal wheat variety for biscuits and pastries production due to its low and acceptable amount of gluten content; also, it is recommended for patients with gluten intolerance since high wheat gluten content is associated with health issues such as celiac disease and gluten intolerance [279, 280, 261, 265, 268]. Consequently, the Radmira and Belyana varieties performed better for bread making and other high-quality gluten products. Most findings have shown that wheat with at least 24% wet gluten is generally considered suitable for bread-making [281 279]. The Belyana variety also exhibited a similar trend to that of Radmira, with its high gluten percentage (Table 3.9)

It was evident that there was statistical variation with all varieties; this is indicative of the effect of genotype (varieties having different pedigrees (parents), which include Radmira (Zlata x Ester varieties), Belyana (Engelina x Ester varieties), and Agros (Zlata x Moskovskaya 56 varieties), including management practices, and environmental variability. In a study by [281, 279], the researchers examined the grain qualities, gluten, and protein components of 78 wheat varieties. Their findings indicated notable variations in the quality traits of gluten and protein components among all genotypes. The impact of genotype × environment was significant on grain quality (gluten and protein), as well as on the levels of glutenin and gliadin, and the ratio of glutenin to gliadin; however, it did not affect globulin. Thus, the influence of genotype and environment on protein and gluten content was significant. The genotype has been identified as the primary factor influencing the quality indicators of wheat [282]. Therefore, genotypes with high-quality gluten could be a viable strategy to enhance bread quality. Our findings suggest that the Agros variety with a low gluten content (20.27%) is ideal for gluten-intolerant persons' consumption, especially for patients with gluten allergies. Our findings align with those from a clinical trial involving non-celiac wheat sensitivity (NCWS), which showed that consuming bread with low gluten and gliadin content led to beneficial alterations in gut microbiota composition in patients [280, 283]. Their investigation involved an extensive analysis of the use of advanced technologies to create wheat lines devoid of immunogenic gluten, along with a thorough examination of their genetic, nutritional, and clinical characteristics. Our findings suggest that Radmira and Belyana varieties are ideal for baking and other industrial purposes. These findings were in analogy with [283], who reported that wheat's gluten content significantly influences bread-making quality. Nevertheless, an excess of gluten is associated with various digestive disorders; hence, Agros can be an ideal variety. Therefore, these findings suggest that improving the quantity and quality of wheat grain and gluten to acceptable levels could have a significant impact on food security, nutritional status, and human health, particularly in developing nations.

Table 3.9 – Influence of three varieties and three cultivation technologies on gluten and protein contents of spring wheat

Treatments	Gluten %			Three years Average	± Basic (%)	Protein %			Three years Average	± Basic %
	2022	2023	2024			2022	2023	2024		
Factor A: Cultivation Technology										
Basic	18.67	18.44	19.93	19.01	-	11.43	12.97	13.65	12.68	-
Intensive	25.10	25.10	20.83	23.68	24.53	13.69	14.30	17.50	15.16	19.55
High -intensive	27.27	27.27	21.20	25.25	32.78	14.10	15.10	17.17	15.46	21.87
P-value	<.001***	<.001***	<.001***	-	-	<.001***	<.001***	<.001***	-	-
LSD 5%	0.09	0.31	0.20	-	-	0.33	0.37	0.42	-	-
Standard error (A)	0.34	0.14	0.09	-	-	0.15	0.16	0.19	-	-
CV%	0.2	0.6	0.4	-	-				-	-
Factor B: Varieties										
Agros	20.27	20.26	20.77	20.43	-18.74	12.17	13.60	15.60	13.79	-7.59
Belyana	23.43	23.43	20.20	22.35	-11.11	12.59	14.73	16.45	14.59	-2.23
Radmira (Standard)	27.33	27.11	21.00	25.15	-	14.47	14.03	16.27	14.92	-
P-value	<.001***	<.001***	0.001***	-	-	<.001***	<.001***	0.002*	-	-
LSD 5%	0.09	0.27	0.23	-	-	0.36	0.16	0.25	-	-
Standard error (B)	0.04	0.12	0.10			0.16	0.07	0.11		
CV%	0.2	0.5	0.5	-	-	1.2	0.5	0.7	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, *=significant, **=very significant, ***=highly significant, ns= not significant.

The study demonstrated that wheat varieties, including Radmira, Belyana, and Agros, could be used to improve the gluten content of other wheat varieties. Therefore, all three varieties are recommended to enhance grain quantity and quality, food security, nutritional status, and human health, especially in developing nations.

In terms of cultivation technologies, the maximum gluten content was observed with high-intensive cultivation technology (27.27% in 2022 and 2023), followed by intensive (25.10% for both 2022 and 2023), and basic technology had the least across all years (Table 3.9). These cultivation technologies influenced the gluten content, with high-intensive technology having the highest average gluten content (25.25%), followed by intensive technology (23.68%). This difference was noted when we calculated the percentage increase over the control; the high-intensity technology increased the gluten percentage by 32.78%. In contrast, intensive technology increased the gluten percentage by 24.53%, compared to basic technology. Therefore, it is evidence that high-intensity technology was effective in influencing high gluten percentage. Our results indicate a significant increase in gluten in all years. The findings demonstrate that the intensity of the agricultural inputs (fertilizers and other crop protection chemicals) is directly proportional to an increase in the gluten content of wheat. Our findings align with those of [284, 279, 280], who reported that increasing agricultural inputs at varying frequencies significantly increases wheat gluten content (11.2%, 5.5%, and 4.5%, respectively). In addition, researchers have opined that the primary objectives in wheat crop production are high grain yield and quality, which includes protein and gluten content. These can be achieved through the application of appropriate mineral nutrients and the control of plant pathogens using integrated management strategies [285]. Our results demonstrate the importance of using agricultural inputs at the proper level, including fertilizers, crop protection chemicals, and varietal selection, in enhancing wheat yield and quality by increasing protein and gluten content through high-intensity and intensive cultivation technologies. Future studies should continue to explore the relationship between cultivation techniques and grain quality, aiming to develop best practices that maximize yield and nutritional value while preserving natural conservation.

3.3.2. The influence of varieties and cultivation technologies on protein content (%)

Our analysis revealed significant variance ($P < 0.001$) in the protein content of the three wheat varieties, indicating that the varietal effect has a considerable influence on protein content. The Radmira variety also had the highest protein content (14.47% in 2022), compared to Belyana (12.59%) and Agros (12.17%). Nevertheless, these varieties had statistically similar protein content values in the same year (Table 3.9). In 2023 and 2024, Belyana achieved the highest protein content of 14.73% and 16.45%, surpassing both Agros and Radmira. Analyzing the three years reveals that Radmira had the highest gluten percentage (14.92%), while Belyana had (14.59%), though statistically similar, and Agros attained the least (13.79%), indicating that the mechanisms of gluten and protein in the Radmira variety are more enhanced than in the other two varieties. There was a decrease in the gluten content of the two new varieties, with Agros (±7.59%) and Belyana (±2.23%). These results suggest an improved mechanism for both gluten and protein synthesis in Radmira, indicating that this variety may possess genetic or biochemical traits that favor higher accumulation of these crucial components (Table 3.9). Our findings concur with those of Iqbal and co-authors, who noted that the protein content in wheat grain ranges from 10% to 18% of its total dry weight and is proportional to its gluten content [286].

The analysis of variance revealed that intensive technology had the highest protein content across years, with 2024 attaining (17.50%) protein; nevertheless, it had statistical similarity with high intensive technology (17.17%). In 2022, high-intensive technology showed the highest protein content (14.10%), which was statistically comparable to intensive technology (13.69 %). However, the two technologies significantly varied ($P<0.001$), with basic technology (11.43%). In 2023, high-intensive technology also attained the highest protein content (15.10%), while the basic technology demonstrated the least protein content in all three years (Table 3.9). On average, High-intensive technology has the highest protein content compared to Intensive and Basic technologies, with a percentage increase of 21.87%. The proteins found in wheat flour play a crucial role in determining its functionality, enabling its application in various food products. Since wheat seed-storage proteins are a critical source of nutrition and energy, they can significantly influence bread-making quality [287]. The proteins are essential for capturing carbon dioxide, facilitating dough development, and maintaining baking quality, owing to their specific qualitative and quantitative traits [288]. Our findings emphasize the importance of selecting the appropriate wheat varieties, particularly for their protein and gluten characteristics. These findings suggest that the Radmira and Belyana varieties can enhance nutritional quality due to their unique genetic characteristics. It can be observed that the production intensity is proportional to the protein content produced. The higher nitrogen level applied to both intensive and high-intensive experimental units enhanced protein biosynthesis, as nitrogen is a crucial factor in protein synthesis. Moreover, the split application of nitrogen ensured that the crop's critical growth stages were synchronized with nitrogen provision, thereby ensuring the abundance of nutrients available for protein synthesis and, consequently, high protein levels. Our results support the view of [265, 279, 280, 261, 268], who reported that as they intensified their various cultivation techniques, they achieved the highest protein content of 18% with the Nemchinovskaya 85 variety. Our results show that high-intensive technology combined with the Radmira and Belyana varieties improves gluten and protein content. Radmira consistently outperformed Agros and Belyana in terms of gluten, indicating its higher genetic potential for quality. High-intensity technology improved wheat quality traits, demonstrating that cultured agronomic technologies enhance wheat quality. However, the gluten content decreased from 2022 to 2024, suggesting that environmental stress may have impacted wheat quality. This research demonstrates that variety and cultivation techniques have a significant influence on the gluten and protein content of spring wheat. Nonetheless, Climate fluctuations continue to challenge wheat production; therefore, it is essential to investigate climate-resilient wheat cultivation.

3.3.3. Interactive effect of three varieties and three cultivation technologies on gluten content (%)

The interactive effect of cultivation technologies and the varieties on gluten content and protein content was determined. These traits are crucial in the food industry, renowned for its functional properties in baking and food processing, hence their assessment (Table 3.10). The analysis of variance reveals statistical significance across all varieties × technology interactions, which were highly significant ($p < 0.001$) from 2022 to 2024. The Radmira variety produced under intensive technology had the highest gluten content (32.2%) and protein content (16.3%) in 2022. In 2023, Radmira variety also exhibited statistical similarities in gluten (32.2%), with the same production technique and (15.7%) protein content with the same intensive production system in 2023, but had a sharp drop in 2024 with gluten content (21,7%), this could be due to climatic variations, soil fertility coupled with drought stress, thought its maintain a better protein content (18.3%) with intensive technology, this indicates that Radmira variety can strive well under the intensive technology systems with regards these traits as shown across all three years (Table 3.10). A more pronounced effect or strong relationship was observed when this variety (Radmira) interacted with intensive technology; hence, on average, it also attained the highest gluten content (28.70%) and protein content (16.77%). This research aligns with the views of [261, 268], who opined that selecting wheat cultivars with high protein content (the total protein generated per unit area) and enhancing nitrogen use efficiency to prevent over-fertilization are essential for improving yield and yield quality traits. Belyana variety produced under high-intensive technology attained the second position for its gluten and attained the same values of (26.1% in 2022 and 2023) and protein content (13.6% and 14.6% in 2022 and 2023). In 2024, the Belyana variety maintained a similar trend, securing its second position in gluten content (20.5%) and protein content (17.4%) with an intensive production system. The lowest gluten content was recorded in 2022 (24.5%) and 2023 (24.5%) with intensive technology. In 2024, we observed a drop in gluten content (22.2%) under high-intensive technology, which was similar to Radmira in the same year (Table 3.10). Agros also have the least protein content across all three years. The interaction effects of Agros x basic technology perfectly mirror the main impact, whereby Agros had the lowest gluten content (20.27%), and basic technology also produced the lowest gluten content (18.67%), as shown in Table 3.9 above.

The interaction of variety and basic technology lowers the gluten content across all years. In terms of the interactive effects, Radmira had (28.70%) gluten content, under Intensive technology (Table 3.10), as well as the highest protein content (16.77%). Additionally, in comparing the cultivation technologies, intensive and high-intensive technologies produce higher protein and gluten content compared with the Basic technology.

Table 3.10 – Interactive effect of three varieties and three cultivation technologies on gluten and protein contents of spring wheat

Parameters	Gluten (%)				Protein (%)			
	2022	**2023**	**2024**	**Three years Average**	**2022**	**2023**	**2024**	**Three years Average**
Treatment interactions								
Agros× Basic	15.8	15.8	19.8	17.13	10.8	12.3	13.0	12.03
Agro×1ntensive	24.5	24.5	20.3	23.10	13.2	14.2	16.8	14.73
Agros× H. Intensive	20.5	20.5	22.2	21.07	12.5	14.3	17.0	14.60
Belyana× Basic	19.1	19.1	19.9	19.37	11.4	14.2	15.5	13.70
Belyana×1ntensive	25.1	25.1	20.5	23.57	12.8	15.4	17.4	15.20
Belyana× H. Intensive	26.1	26.1	20.2	24.13	13.6	14.6	16.5	14.90
Radmira× Basic	21.1	20.4	20.1	20.53	12.1	12.4	12.5	12.33
Radmira×1ntensive	32.2	32.2	21.7	28.70	16.3	15.7	18.3	16.77
Radmira× H. Intensive	28.7	28.7	21.2	26.20	15.0	14.0	18.0	15.67
P-value	<.001***	<.001***	<.001***	-	<.001***	<.001***	<.001***	-
LSD 5%	0.16	0.38	0.37	-	0.42	0.39	0.45	-

Standard error (AxB)	0.13	0.22	0.29	-	0.15	0.20	0.21	-
CV%	0.6	0.9	1.4	-	1.1	1.4	1.3	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

However, a decline in protein content was observed across years, particularly during the 2024 growing season, for gluten content (Table 3.10). Our findings demonstrated that using the right amount of NKP fertilizers and applying them in a split manner ensured the enhancement of wheat quality, thereby enriching the abundance of nutrients available for gluten and protein synthesis, which in turn enhanced these traits. Our findings align with those of [265, 279, 280], who have indicated that intensifying diverse cultivation techniques increases the gluten and protein contents. The interactive effect between variety and cultivation method profoundly influences wheat quality, with Radmira and Belyana, combined with Intensive and High-Intensity technology, yielding the most favorable results, followed by Agros and intensive technology. However, breeders should focus on addressing environmental instability to achieve wheat varieties that require adaptive mechanisms. This research reinforces the use of intensive and high-intensity cultivation methods and highlights the significance of genotype selection and environmental management strategies in wheat production.

The study demonstrates that the interaction between variety and cultivation technology has a significant influence on spring wheat yield and quality. Agros and Belyana demonstrated stable yields, while Radmira excelled in quality traits such as gluten and protein. Intensive and high-intensive technologies enhanced both productivity and grain quality, though diminishing returns occurred at the highest input levels. Optimal performance requires matching genotypes with appropriate agronomic practices, highlighting the need for integrated, environment-adaptive strategies to ensure sustainable wheat production under variable climatic conditions.

CHAPTER FOUR

4.0. DISEASE INCIDENCE AND SEVERITY ANALYSIS ACROSS GROWTH STAGES AND CULTIVATION TECHNOLOGIES (2022–2024)

4.1. The Influence of cultivation technologies and varieties on the incidence and severity of three key wheat diseases (2022 to 2024)

Generally, the Moscow region experienced notable climatic variations from 2022 to 2024, which significantly influenced the incidence of diseases in spring wheat. The weather trends included consistent warming, extreme temperature deviations in 2023 and 2024, and highly variable precipitation patterns. Spring temperatures from 2022 to 2024 showed a consistent warming drift, with the most notable changes occurring in 2023 (March, +5.2°C) and 2024 (April, +6.0°C; May, +4.4°C). Summer temperatures in 2024 showed the most significant anomalies, particularly in June (+3.1°C) and July (+5.2°C). While 2022 remained consistently warm, 2023 experienced more moderate summer conditions. Precipitation patterns varied significantly over the three years. Dry periods were observed in 2022 (March, second ten-day period; June, third ten-day period; August, all ten-day periods), 2023 (April and May, second ten-day periods), and 2024 (March, first and second ten-day periods; May, third ten-day period). Wet periods were recorded in 2022 (April, first ten-day period; May, third ten-day period), 2023 (March, second and third ten-day periods; June, third ten-day period; July, second and third ten-day periods), and 2024 (April, second ten-day period; June, second ten-day period).

These variations in weather conditions established a dynamic environment for disease development, particularly for powdery mildew, *Septoria* leaf blotch (SLB), and *Fusarium* head blight (FHB) disease of wheat. The study considers the impact of wheat varieties, cultivation technologies, and the year effect on controlling these diseases.

4.2. The influence of spring varieties and cultivation technologies on the incidence and severity of Septoria leaf blotch (*Zymoseptoria tritici*) (SLB)

SLB is a fungal disease caused by *Z. tritici*; (ST) is a significant threat to wheat production in Russia, affecting yield and grain quality [180]. Effective management relies on resistant varieties and optimizes agronomic practices [289]. Between 2022 and 2024, a combined ANOVA revealed significant effects of cultivation technology ($P < 0.001$) on SLB, but no significant effect was observed for varieties (Table 3.11). However, the three-year average of the Belyana variety showed the lowest mean incidence (30.23%) and severity (1.82%), suggesting better resistance. In comparison, Agros' incidence was (34.17%) with a severity rate of (1.88%), and Radmira (34.81%) with a severity of (1.94%), which shows that Radmira was more susceptible. When the analyses for percentage reduction for variety and cultivation technology were carried out, results revealed that Intensive cultivation reduces the disease load by (45.15%) with a severity reduction of (19.89 %), compared to high-intensive and basic technology.

The findings also reveal that Belyana was resistant to SLB (±13.16%), compared to Agros and Radmira varieties. On average, Intensive technology remarkably reduced disease incidence (23.84%), rating it as a reduction over control (± 45.15%) and severity (1.73%), rating it as a reduction over control (± 19.89%), compared to Basic (43.47%) incidence and a severity rate (2.15%).

On average, High-intensive treatment yielded intermediate results (31.90%, 1.77%). SLB pressure peaked in 2023 (35.56% incidence, 1.99% severity) but declined sharply in 2024 (25.97%, 1.58%). This could be due to the improved cultivation techniques, varietal selection, and favorable weather conditions. Both technology ($P < 0.001$) and year ($P < 0.001$) effects were highly significant, underscoring the role of integrated management in disease control.

Our findings suggest that to control SLB incidence, severity, and year impact, the Belyana variety, intensive cultivation technology, and 2024 weather conditions are favorable for managing and reducing the SLB disease severity threshold to a more acceptable level in plant pathology (Table 3.11). Our research results support the previous findings by [188, 289], who reported a similar trend: using resistant cultivars, fungicides, and crop rotation can minimize disease invasion, thereby reducing losses to most cereal crops.

Overall, our findings demonstrated that cultivation technology had a greater influence on SLB control than wheat variety. An intensive cultivation approach proved to be the most effective management technique, and Belyana emerged as the most resistant variety.

The declining disease trend suggests that management has improved, and favorable weather conditions have prevailed over time. Findings have shown that intensive technology could be relevant in the field for all cereal disease management programs, and the Belyana variety could be utilized for further hybrid-resistant breeding programs in Russia and worldwide.

Table 3.11 – The effect of three spring wheat varieties and three cultivation technologies on the prevalence (incidence) and severity of Septoria leaf blotch (SLB) 2022-2024

Treatments	Septoria leaf blotch disease incidence (%)			Three years Average	± (%) Reduction vs. Basic	Septoria leaf blotch disease severity (%)			Three years Average	± (%) Reduction vs. Basic
	2022	2023	2024			2022	2023	2024		
Factor A: Cultivation Technology										
Basic	46.25	45.83	38.33	43.47	-	2.00	2.00	2.46	2.15	-
Intensive	28.47	23.06	20.00	23.84	45.15	1,76	1.74	1.71	1.73	19.89
High -Intensive	34.17	35.56	25.97	31.90	26.62	1.74	1.99	1.58	1.77	17.80
P-value	0.010**	<.001***	0.002**	-	-	0.080ns	0.004**	<.001**	-	-
LSD 5%	8.31	10.25	5.77	-	-	0.25	0.28	0.11	-	-
Standard error (A)	3.67	2.14	2.54	-	-	0.12	0.12	0.06	-	-
CV%	10.1	6.1	9.1	-	-	6.0	6.0	2.7	-	-
Factor B: Varieties										
Agros	36.25	37.08	29.17	34.17	1.86	1.80	2.02	1.83	1.88	2.92
Belyana	33.06	32.64	25.00	30.23	13.16	1.73	2.04	1.69	1.82	6.19
Radmira (Standard)	39.58	34.72	30.14	34.81	-	1.98	2.11	1.73	1.94	-
P-value	0.084ns	0.538ns	0.242ns	-	-	0.028*	0.533ns	0.344ns	-	-
LSD 5%	5.78	4.84	7.45	-	-	0.17	0.20	0.23	-	-
Standard error (B)	2.55	4.52	3.29			0.07	0.09	0.10		
CV%	7.0	13.0	11.7	-	-	4.0	4.4	5.9	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

4.2.1. The average influence of spring wheat varieties and cultivation technologies on the incidence of Septoria leaf blotch (SLB) disease of wheat assessed under four growth stages.

SLB is a foliar disease affecting wheat worldwide. A field evaluation was conducted over three years to assess the effectiveness of three cultivation technologies and three spring wheat varieties in controlling SLB disease across the developmental growth stages (stem elongation, Booting, heading/flowering, and Milk/dough development) of spring wheat. The findings demonstrated distinct variations in the susceptibility and resistance of these varieties, highlighting the need for tailored cultivation practices to manage disease (Figure 3.1).

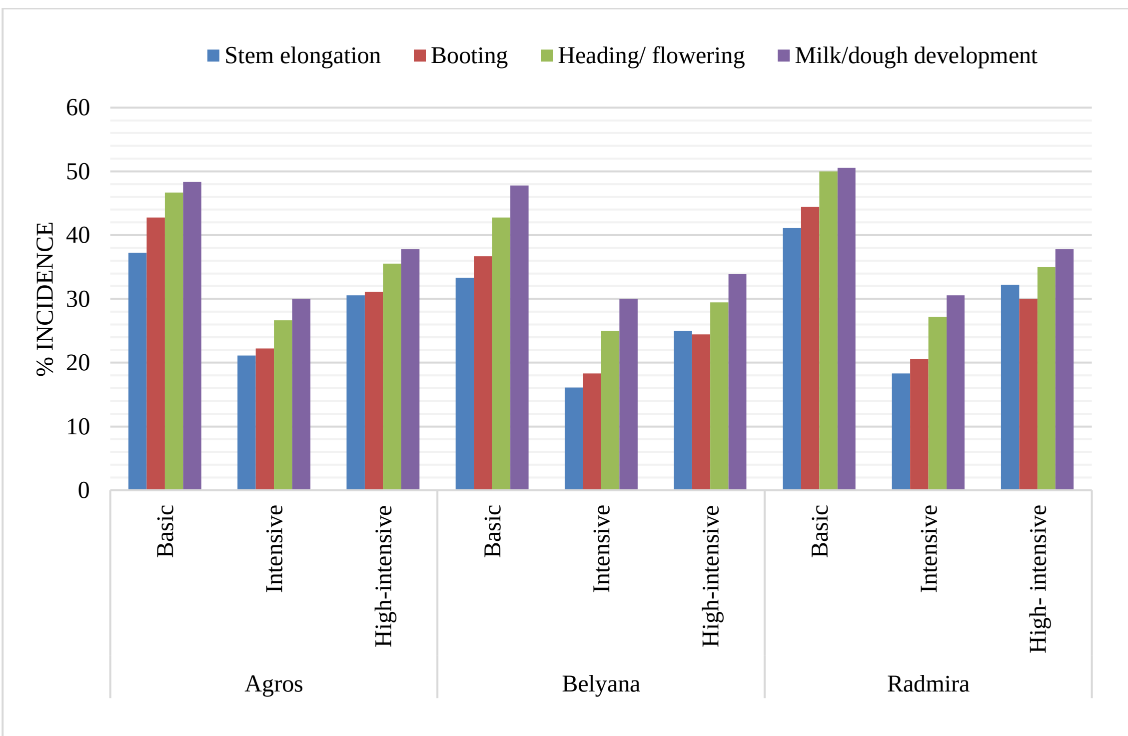


Figure 3.1. Average incidence of SLB disease as influenced by spring wheat varieties and cultivation technologies 2022-2024

In assessing the disease progress under the three technologies across the various growth stages of spring wheat, it was observed that the incidence of SLB increased over time in all three wheat varieties (Figure 3.1). From the stem elongation, booting, heading/flowering, and milk/dough development stages, all three varieties exhibited varying levels of incidence, ranging from 16% to 50.56%, as they progressed from the stem elongation to the Milk/dough stage. In analyzing disease incidence for each growth stage (stem elongation), Belyana exhibited the lowest disease incidence of 16.11% under intensive cultivation, followed by Radmira (18.33%) under intensive technology, and Agros had the highest incidence (21.11%). In contrast, basic and high-intensity technologies had the highest disease incidence, as shown in Figure 3.1. In the booting stage, Belyana (18.33%) exhibited the lowest SLB incidence, compared to Radmira (20.56%) and Agros (22.22%) under intensive technology. The same trend occurs with high-intensive technology, which ranks second in reducing SLB disease incidence. In contrast, basic technology continues to record a high incidence across all growth stages and varieties. At the heading/ flowering stage, the Belyana variety surpasses both Agros and Radmira when cultivated with an intensive system. However, Agros led Radmira in terms of SLB incidence. At the final evaluation stage (mild/dough), Belyana and Agros recorded the same incidence levels, both rated at 30.00%.

All varieties exhibited distinct resistance under intensive technology, resulting in a lower disease incidence percentage of SLB in all evaluated varieties compared to those under high intensive and basic technology. Radmira consistently demonstrated the highest incidence rates, indicating greater susceptibility to infection, while Belyana maintained the lowest incidence throughout the evaluation stages, suggesting stronger resistance. Agros showed intermediate susceptibility, with incidence levels between Belyana and Radmira. Figure (3.1). In evaluating the effect of cultivation technologies and varieties on reducing SLB disease incidence in spring wheat, the findings indicated that intensive cultivation technology was a more effective management technique in lowering the percentage incidence of SLB across all three varieties. In evaluating the varieties, the analysis of variance confirms that Belyana exhibited high resistance, yielding the lowest percentage of incidence across the stem elongation to milk/dough development stages. Agros displayed intermediate susceptibility, with incidence levels falling between those of Belyana and Radmira. This could be related to the crop protection chemicals used in intensive technology and the genetic makeup of the Belyana variety. The findings demonstrated that intensive technology and the Belyana variety could be the most effective technique and variety in controlling SLB disease at an acceptable threshold. The findings align with [182, 184, 191], stating that integrated disease management and resistant varieties are crucial in managing most cereal diseases. Farmers and wheat breeders could adopt the Belyana variety and intensive cultivation technology in wheat production, including breeding programs that focus on disease-resistant varieties.

4.2.2. The average influence of spring wheat varieties and cultivation technologies on the severity of Septoria leaf blotch disease of wheat assessed under four growth stages

When accessing the SLB disease in the field, we followed the procedure outlined by [187]. The incidence of Septoria leaf blotch was processed based on the presence and absence of disease within all trial plots. Disease incidence and severity were assessed visually in each field in an "X" fashion by taking 25 random plants within a quadrat (0.5 m × 0.5 m) in each plot. Disease incidence was calculated as the percentage of infected plants by the total number of plants assessed, and samples of affected leaves are presented in Figure 3.3.

The mean severity of SLB was evaluated by comparing the proportion of leaf area affected by lesions, as shown in Figures 3.2 and 3.3 from 2022 to 2024. At the stem elongation stage, the percentage severity was low across all varieties, varying between 1.60% (Agros), 1.27% (Belyana), and 1.39% (Radmira) when accessed under the intensive technology. During the booting stage, the severity percentage remains stable, with all varieties showing a minor increase in severity (Figure 3.2), except for the basic technology, which recorded the highest severity among all varieties. At the heading/flowering stage, the analysis of variance revealed a slight increase in the percentage severity across all varieties;

nonetheless, this increase was more evident with Radmira (1.88%), followed by Agros (1.84%), and Belyana had the least severity of (1.77%) when the intensive method was employed. At the milk/dough development stage, the Radmira variety exhibited the highest percentage severity scores (2.56% under basic technology, 1.97% for intensive, and 1.97% for high-intensive practices), indicating its inability to suppress lesion expansion. Agros displayed a moderate percentage severity, which was consistent with its intermediate incidence. Belyana recorded the lowest severity, which aligns with its lower incidence (Figure 3.1 above) and demonstrates high resistance to SLB disease progression (Table 3.2).

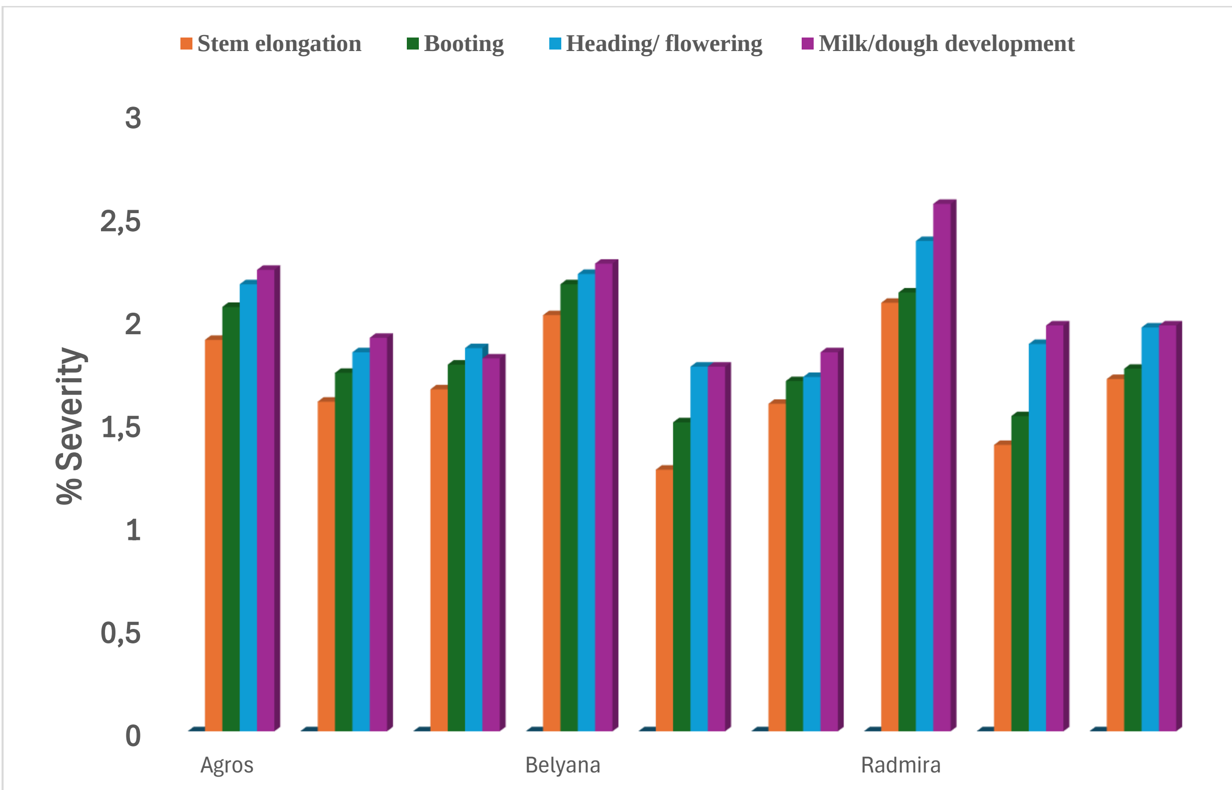


Figure 3.2. Average Severity of Septoria leaf blotch disease on spring wheat varieties and cultivation technologies 2022-2024.

The study observed a strong correlation between SLB percentage, disease incidence, and severity across all varieties. Radmira, which had the highest incidence, also exhibited a high severity rate, suggesting ineffective resistance mechanisms. Belyana, with the lowest incidence and severity, demonstrated superior genetic resistance to infection and lesion development. Agros, however, showed moderate incidence and severity, highlighting its balanced but less robust resistance. The progression of SLB incidence and severity aligns with the characteristics of Zymoseptoria tritici, which experiences a latent phase before sporulation and lesion expansion. The pathogen remains latent early in the crop cycle (42–56 days), resulting in low severity despite rising incidence. These results could be related to somewhat conducive environmental conditions, including high humidity and moderate temperatures, and the crop protection techniques employed in the study most have contributed to lessening the lesion spread and disease development; our results correspond with [290, 291]; they opined that the increasing trend in the percentage disease incidence over time align with the life cycle of *Z. tritici*, a pathogen that thrives in favorable environmental conditions, exceptionally high humidity, and moderate temperatures. Furthermore, the Belyana variety consistently had low incidence and severity rates, suggesting effective resistance mechanisms, which may be associated with its genetic traits. Resistance genes such as SLB6 and SLB16q can limit infection rates and lesion expansion [292]. In contrast, the Radmira variety exhibited high susceptibility, which could be due to the absence of these genes or other effective defense mechanisms. Agros, with moderate performance, may have partial resistance, providing average protection against SLB.

Our findings emphasize the importance of resistant varieties like Belyana in managing SLB, particularly in regions with high disease pressure. Combining resistant varieties with intensive cultivation management strategies, such as fungicide application and crop rotation, could significantly reduce yield losses [188]. Radmira, given its high susceptibility, requires intensive management to mitigate its vulnerability. The observed varietal differences align with findings by [293], who reported that resistant cultivars effectively reduce incidence and severity. Fones [291] also noted that resistant varieties enhance yield stability by minimizing the impact of SLB. Furthermore, the progression of disease severity observed in this study supports earlier research highlighting the essential role of environmental factors in disease development [294]. High humidity and frequent rainfall during the study period most likely exacerbated SLB severity, particularly in susceptible varieties like Radmira. This emphasizes the need to consider local environmental conditions when selecting wheat varieties and designing disease management programs. Our study highlights the contrasting susceptibility of three spring wheat varieties to Septoria leaf blotch. Radmira demonstrated the highest susceptibility, with consistently high incidence and severity, making it unsuitable for regions with high SLB pressure without intensive management. Belyana exhibited the most vigorous resistance, with the lowest incidence and severity rates, and thus attained the highest wheat yield value of 4.64 t ha^{-1}, making it a viable option for sustainable wheat production. Agros showed intermediate performance, offering a balanced choice in moderately favorable conditions. These findings emphasize the need for breeding programs to focus on incorporating resistance genes in most wheat varieties and for farmers to adopt the best intensive cultivation technology to mitigate the impact of SLB.

Figure 3.3. Sample symptoms of Septoria leaf blotch identified in the experimental plots 2022-2024.

4.2.3. Three-year interactive effect of spring wheat varieties and cultivation technologies on the percentage severity of Septoria leaf blotch

Figure 3.4 represents the three-year interaction effect of SLB disease severity on the three wheat varieties and three cultivation technologies studied from 2022 to 2024. The combined ANOVA results for 2022 indicated that the highest severity of SLB was observed in Basic cultivation technology with the Radmira variety (2.25%), followed by Basic Belyana (1.95%) and Agros (1.82%). In addition, the intensive and high-intensive cultivation techniques showed low percentage severity across all varieties. However, the Belyana variety recorded the lowest severity score (1.58%) among all treatments with intensive technology, indicating that these technologies may mitigate disease in spring wheat production. In the 2023 cultivation season, there was a general increase in SLB severity compared to 2022, with Basic Technology and Radmira showing a (2.53%) severity rate, and Belyana Basic (2.50%) showing high susceptibility; however, Agros had the lowest (2.63%). Interestingly, the statistical analysis reveals that the Belyana (1.70%) and Radmira (1.70%) varieties recorded the same level of interaction severity in 2022. They showed the lowest disease severity rate under intensive cultivation technology, indicating variety-specific resistance when combined with this method. There was a significant decrease in SLB severity across most experimental plots in 2024 compared to 2023. The analysis of variance shows that the Belyana variety (1.45%) recorded the lowest percentage severity under intensive technology (Figure 3.4). The consistent performance of Belyana under intensive methods suggests that this variety and intensive cultivation method could be an essential practice in combating SLB disease of wheat. Findings demonstrated that Basic cultivation constantly resulted in high SLB severity rates across all varieties. At the same time, intensive and high-intensive technologies demonstrate sufficient mitigation strength in reducing the percentage severity impact across all varieties. The findings align with existing studies that emphasize the role of cultivation intensity in managing SLB severity. According to [295, 296], intensive and high-intensive agricultural practices, including optimized fertilization and disease management strategies, can significantly reduce the prevalence of *Z. tritici*. The result also shows significant improvement under intensive practices with Belyana. At the same time, Agros exhibited moderate stability across all years, which indicates genetic differences in SLB resistance among wheat varieties. The lower severity in Intensive x Belyana is consistent with [297], who reported moderate resistance of wheat species under controlled field conditions. It is worth noting that in 2023, SLB disease severity was high, possibly due to environmental factors or an increase in the pathogen's virulence. Findings support [298, 295], who noted that wetter growing seasons correlate with higher SLB outbreaks due to increased leaf wetness periods conducive to fungal proliferation. The yearly variations in 2023 were profound, which may be due to climatic fluctuation (Figure 3.4). Our findings support [299, 298], who noted that wetter growing seasons correlate with higher SLB outbreaks due to increased leaf wetness periods conducive to fungal spread.

This study revealed important insights into sustainable wheat production by demonstrating how different cultivation technologies influence SLB incidence and severity across various varieties and environmental conditions. The findings highlight the importance of implementing optimal agronomic practices. By utilizing intensive or high-intensive cultivation methods, especially for the varieties in this study that show positive responses in these systems, farmers can effectively reduce yield losses attributed to SLB. The findings emphasize the significance of breeding strategies. The varying responses of different varieties suggest that enhancing the genetic resistance of susceptible varieties, like Radmira, could reduce reliance on chemical controls, promoting more sustainable agricultural practices. Furthermore, the findings offer valuable insights for agricultural extension services to promote the adoption of best practices in SLB disease management and to support the incorporation of environmental monitoring to anticipate high-risk periods for disease outbreaks.

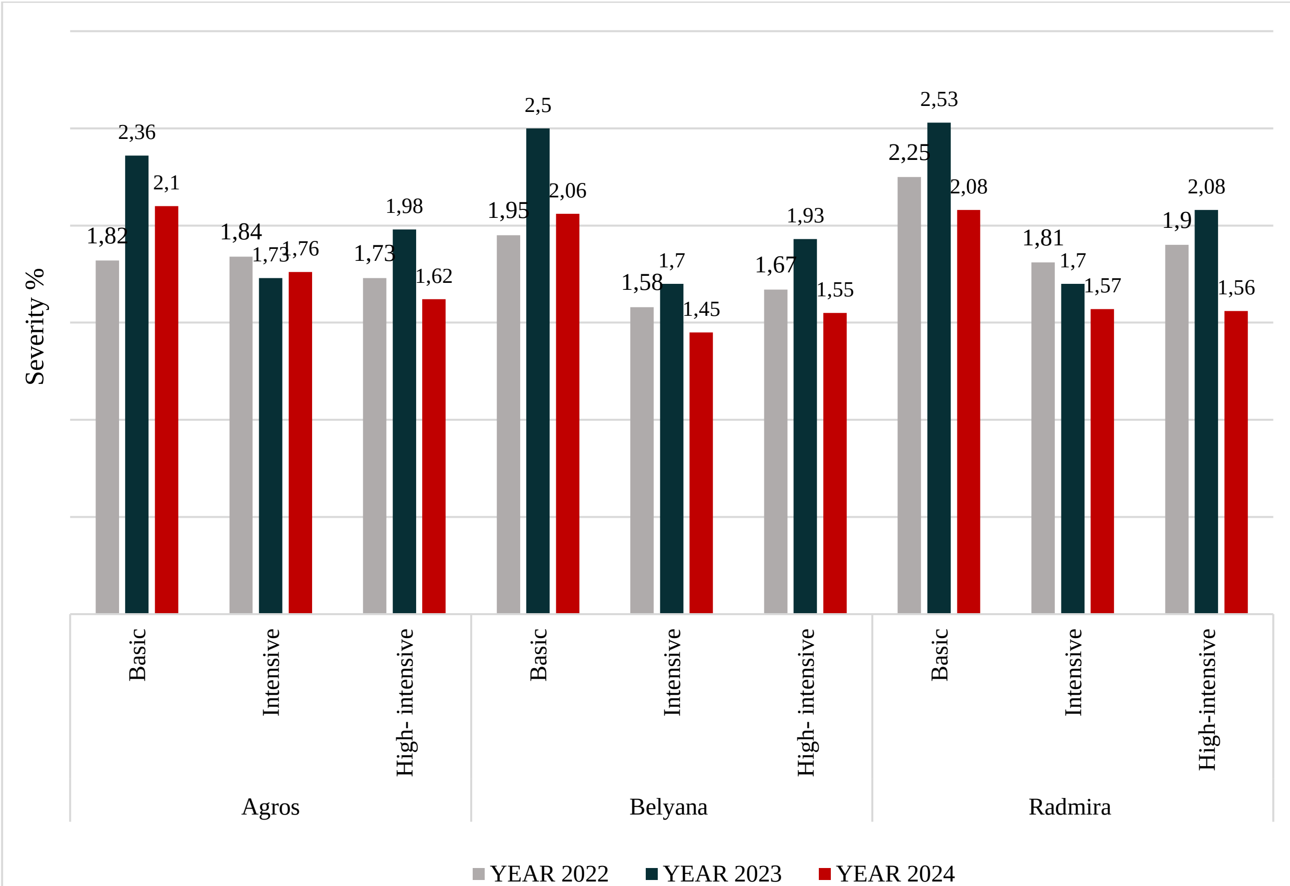


Figure 3.4. The yearly average interactive severity of Septoria leaf blotch on varieties, cultivation technologies, and years.

The yearly fluctuations in disease severity highlight the need for further investigation into the relationship between climate change and SLB epidemiology, as well as the development of adaptive management strategies to address evolving conditions. The study emphasizes the relationship between cultivation practices, varietal selection, and environmental factors in managing Septoria leaf blotch in wheat. It offers harmonized cultivation techniques for improving disease resistance and crop productivity.

4.3. The influence of spring wheat varieties and cultivation technologies on powdery mildew disease incidence and severity of wheat

Wheat powdery mildew (WPM) is a significant fungal disease affecting wheat, primarily caused by the pathogen *B. graminis* f. sp. *tritici*. It is an important disease of wheat that affects all above-ground plant parts and has been reported to impact wheat production globally, leading to substantial yield and quality losses in wheat crops [199, 298]. WPM incidence has been reported to increase from 15% to 30% in several regions of Russia [298, 300]. According to [300], WPM severity has been estimated to increase yield losses in winter wheat by 35% to 45% in the United States. The symptoms of powdery mildew appear as fluffy, white, powdery growths of fungal spores on the leaf surface and in conducive conditions on lawns and glumes of the head. Early symptoms can appear as yellow flecks on leaves before mycelial growth occurs. Symptoms typically progress from lower to upper leaves (spots on stems and leaves). However, the infection can occur at any stage throughout the season, provided WPM spores are present, and conditions are favorable, which can severely impact photosynthesis and overall plant health. This study evaluates the impact of three spring wheat varieties and three cultivation technologies in reducing wheat powdery mildew (WPM) incidence and severity from 2022 to 2024 (Table 3.12).

Cultivation technology significantly influenced disease ($P<0.001$). On average, Intensive treatment recorded the lowest average incidence (23.01%) and severity (1.62%), while Basic showed the highest incidence (37.96%) and severity (2.07%). Varietal differences were not statistically significant ($P > 0.05$). Although on average in three years, Radmira exhibited the lowest mean severity (1.72%), despite a slightly higher incidence (29.81%), this suggests tolerance consistent with findings in [199, 298]. Belyana (28.75%) recorded the lowest incidence and performed better under Intensive technology, hinting at possible resistance genes. In analyzing for percentage reduction over control, findings demonstrated that intensive technology reduces WPM by (± 39.39%) in incidence and severity (± 21.45%). In comparison, highly intensive technology reduces WPM by (± 29.52%) in incidence and severity (± 17.58%) compared to the control treatment. Varietal effect also reveals that Belyana reduces WPM incidence by (± 3.57%) and severity by (± 6.77%) compared to Agros, which has (± 2.17%) incidence and (± 6.58%) severity over the Radmira variety. Disease pressure peaked in 2023, with Radmira recording 32.92%

incidence and 2.04% severity. This could be due to favorable environmental conditions for WPM.

Results highlight Intensive management as key for disease suppression and Radmira/Belyana as valuable genetic resources for breeding WPM-resilient wheat. The result is consistent with [199, 298], who investigated 23 spring wheat cultivars and found that 14 showed high resistance to WPM, compared to the remaining nine. Nonetheless, it is also important to note that the Belyana variety shows less disease incidence under intensive technology.

This could be due to the presence of powdery mildew resistance genes in the Belyana varieties, which may have been incorporated into the breeding program. The finding suggests that Belyana resistance genes in wheat breeding may be a viable option for obtaining effective cultivars with resistance to powdery mildew attacks, particularly in regions with a high incidence of WPM disease. The three cultivation technologies exhibited significant influence on the incidence and severity of WPM disease. Among the three cultivation technologies, intensive technology consistently proved the most effective, with the lowest average incidence (23.01%) and severity (1.62%), suggesting it is a highly effective management approach for managing powdery mildew of wheat.

It is, however, essential to note that basic technology consistently performed poorly, with high incidence levels (37.96%) and severity (2.07%) across all varieties, underscoring the importance of adopting more advanced cultivation practices (Table 3.12). Year-to-year variability also significantly affected WPM disease management. The 2023 growing season exhibited a high incidence (30.46%) and severity (2.06%) of powdery mildew attacks, indicating a susceptible year across all varieties and technologies. In comparison, the data from 2022 and 2024 showed that environmental factors significantly affected disease progression (Table 3.12).

Table 3.12 – The effect of three spring wheat varieties and three cultivation technologies on the prevalence (incidence) and severity of Powdery mildew disease 2022-2024.

Treatments	Powdery mildew disease incidence (%)			Three years Average	± (%) Reduction vs. Basic	Powdery mildew disease severity (%)			Three years Average	± (%) Reduction vs. Basic
	2022	2023	2024			2022	2023	2024		
Factor A: Cultivation Technology										
Basic	37.64	38.75	37.50	37.96	-	1.69	2.38	2.13	2.07	-
Intensive	24.86	23.06	21.11	23.01	39.39	1.46	1.81	1.60	1.62	21.45
High - Intensive	24.44	29.58	26.25	26.76	29.52	1.61	1.99	1.51	1.70	17.58
P-value	<.001***	0.001***	<.001***	-	-	0.015*	0.002**	<.001***	-	-
LSD 5%	3.028	3.98	3.51	-	-	0.120	0.17	0.146	-	-
Standard error (A)	3.34	1.76	1.54	-	-	0.05	0.07	0.06	-	-
CV%	4.6	5.8	5.5	-	-	3.3	3.7	3.7	-	-
Factor B: Varieties										
Agros	31.39	26.67	29.44	29.17	2.17	1.69	2.03	1.79	1.84	6.58
Belyana	27.22	31.81	27.22	28.75	3.57	1.67	2.12	1.73	1.84	6.77
Radmira (Standard)	28.33	32.92	28.19	29.81	-	1.41	2.04	1.72	1.72	-
P-value	0.107ns	0.129ns	0.342ns	-	-	0.058ns	0.787ns	0.311ns	-	-
LSD 5%	4.18	6.93	3.67	-	-	0.246	0.39	0.12	-	-
Standard error (B)	1.84	3.06	1.62			0.12	0.17	0.05		
CV%	6.4	10.0	5.7	-	-	6.8	8.4	2.9	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns=not significant, ns= not significant, * =significant, **=very significant, ***=highly significant

These findings align with [298], who stated that a conducive climate, characterized by mild temperatures, high relative humidity, and wind-driven spore dispersal, can create optimal conditions that play a crucial role in the epidemiology of WPM disease outbreaks.

Our research demonstrated that disease incidence and severity gradually increased over time, reaching their peak, and reflecting the progressive nature of powdery mildew. At the early stages of evaluations, all disease pressures were low, which can be attributed to the early intervention of the applied treatment. These findings underscore the importance of early disease management intervention in preventing severe outbreaks of WPM disease, as WPM disease symptoms are shown in Figure 3.5.

Figure 3.5 Powdery mildew identified in the experimental wheat canopy and on leaves.

Overall, these findings suggest that integrating resistant varieties like Belyana and Radmira with intensive cultivation technologies could provide an optimal strategy for reducing the effect of powdery mildew on spring wheat crops, as shown in Table 3.12.

4.3.1. The average influence of spring wheat varieties and cultivation technologies on wheat powdery mildew (WPM) incidence assessed under four growth stages

The analysis of variance exhibited a significant effect (P<0.05) between varieties and cultivation technologies, under key growth stages, in reducing the incidence of WPM disease. The worldwide population increase and rising food demand have made the production of wheat and the management of pests and diseases a prominent research topic in agriculture. Figure 3.6 illustrates the effect of cultivation technology and spring wheat varieties in reducing the average incidence of WPM disease on varieties, under critical growth phases. The ANOVA result indicates that throughout the four critical growth development stages ranging from stem elongation, booting, heading/flowing, and milk/dough development, the Agros variety demonstrated a low incidence rate when cultivated under the intensive technology; this was evidenced in the stem elongation as it obtains (17.22%) WPM disease incidence, and its incidence rate increase gradually by end early milk/ dough stage shows (27.22%). When correlating the disease progress over time, it was evident that the Agros variety showed only a 10.00% disease increment compared to Belyana (11.11%) and Radmira, which were highly susceptible (12.23%) from the first stage of evaluation to the final stage of the disease scoring and recording. Findings indicate that Agros and Belyana exhibited less mean incidence under intensive technology and could be more resistant to WPM disease; this can be attributed to the genotypic traits of these varieties. Regarding technology, the basic cultivation technology displayed high incidence rates across all varieties and growth development stages. However, with the basic production system, the Agros variety shows the highest incidence of 45.56% at the milk/dough stage.

Belyana incidence rate was more moderate compared to the Radmira variety. This illustrates the responsiveness of disease interaction at each critical growth stage of wheat deployment, underscoring the need for a more integrated approach and resistant varieties in the wheat production system (Figure 3.6). The result demonstrated that the varietal effect appeared more dominant, with the Belyana and Agros varieties showing high potential resistance when combined with intensive technology. The intensive cultivation technology has been revealed to be the most appropriate management technique for mitigating WPM disease incidence and severity before they reach a critical stage that could be hard to manage. Findings support the views of [199, 213, 207, 225], stating that the varietal effect and integrated approach in wheat production can considerably decrease wheat powdery mildew disease to an acceptable level, thereby leading to high-yield and quality seeds, as shown in Figure 3.6.

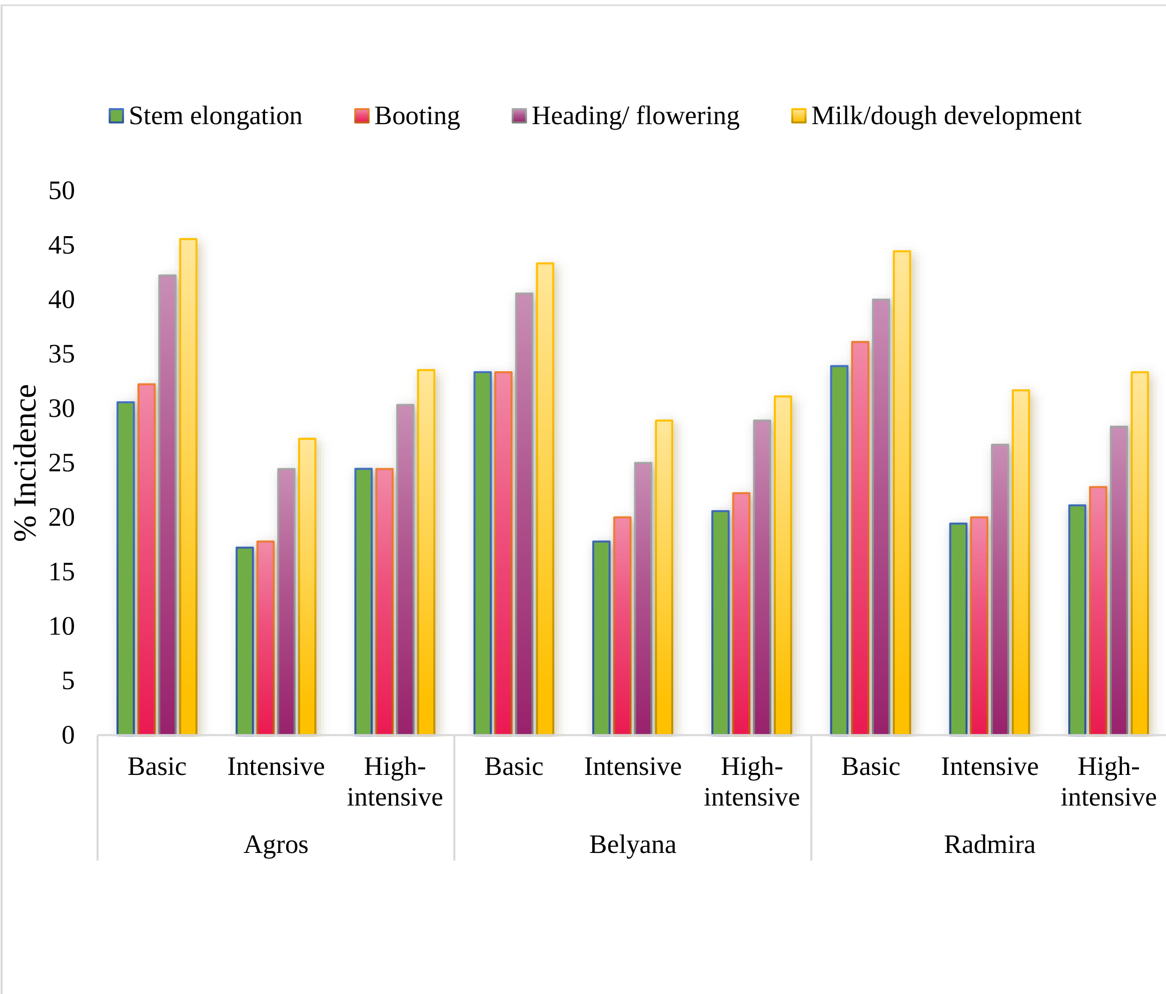


Figure 3.6. Powdery mildew disease average incidence across wheat growth stages 2022–2024

4.3.2. The average influence of spring wheat varieties and cultivation technologies on the severity of powdery mildew disease of wheat as assessed under four growth stages

The influence of spring wheat varieties and cultivation technologies on the severity of powdery mildew disease (WPM) shows no significant effect across all three wheat varieties Figure 3.7; however, cultivation technologies exhibited significant statistical differences over time. Basic technology showed the highest disease severity across all varieties. Moving forward, intensive and high-intensive technologies appear to perform better across all varieties by maintaining low severity rates of WPM disease. As shown in Figure 3.7, Agros under the intensive production system continue to show low severity at the early stages of disease appearance (stem elongation 1.53%, booting 1.57%). At the heading/flowering and milk/dough stages, the high-intensive technology also shows a lesser severity with the Agros variety (1.77%), suggesting that these technologies can suppress the disease load, leading to better yields. The analysis also reveals low WPM disease severity with Belyana (1.67%) under both intensive and high-intensive technologies (1.56%). The study has demonstrated that cultivation intensity, resistant cultivar selection, and early fungicide application are essential and effective in controlling WPM disease. This reduction in WPM disease severity could be attributed to the early fungicide treatment used in this study, which led to a noticeable decrease in the infection rate compared to basic technology. Similarly, previous studies have reported that early fungicide application reduces WPM disease severity on the lower leaves and affects grain yield [301, 302, 203]. Overall, cultivation technology had a more considerable influence on WPM control. Farmers considering fungicide application for WPM disease control should evaluate disease severity early and plan accordingly, as shown in Figure 3.7.

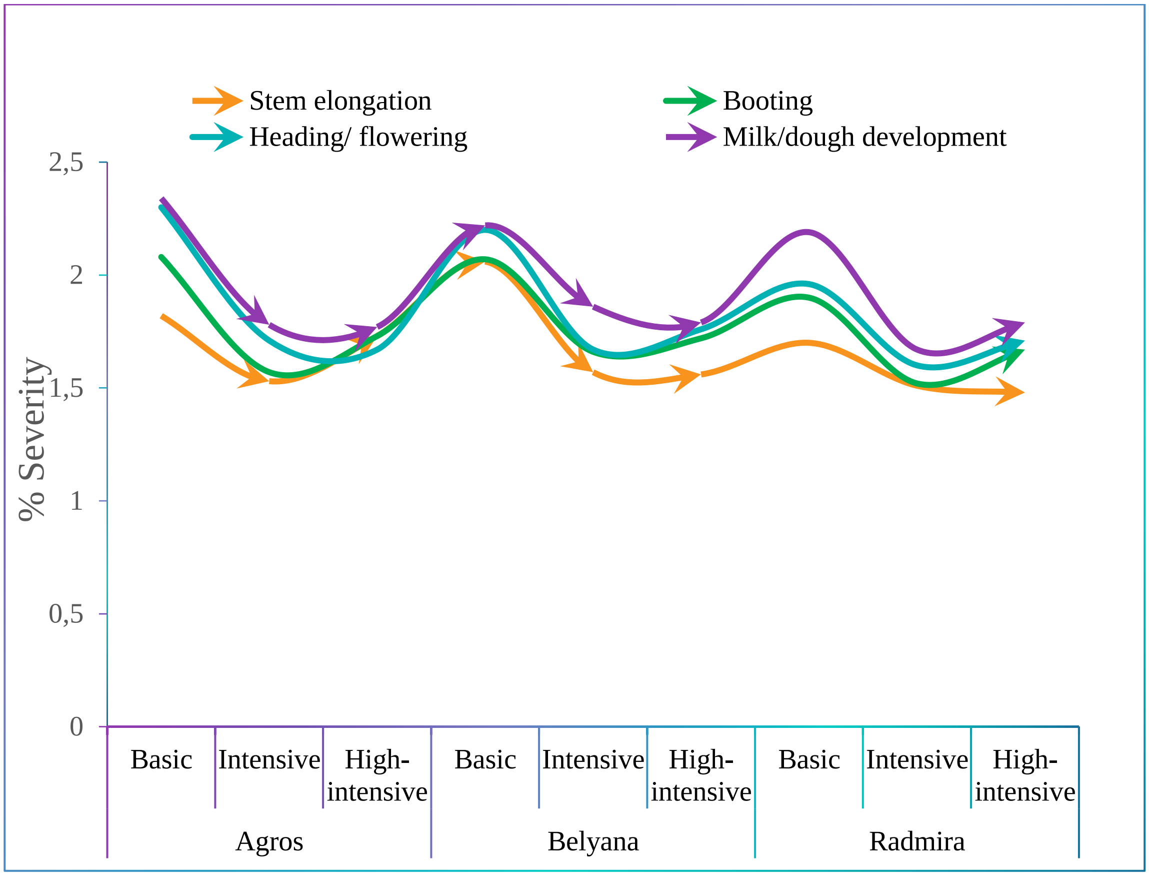


Figure 3.7. Average severity of powdery mildew disease across wheat growth stages 2022–2024.

4.3.3. Three-year interactive effect of spring wheat varieties and cultivation technologies on the percentage severity of wheat powdery mildew

Figure 3.8 presents the interactive effect of WPM on yearly variation, cultivation technologies, and wheat varieties. The ANOVA analysis indicated that the severity of WPM fluctuates across the years (2022-2024) in all wheat varieties and cultivation technologies. Findings reveal that the highest disease severity was recorded in 2023, while 2022 recorded the lowest severity rates, as shown in Figure 3.8. Results suggest that environmental factors might have significantly influenced the high disease severity in 2023. Comparative analysis of cultivation technologies shows that the basic technology was highly susceptible to WPM across all years and varieties. Conversely, the intensive and high-intensive techniques consistently exhibited a low severity rate of WPM, demonstrating the effectiveness of fungicide timing and the other harmonized techniques used in the study in controlling WPM disease. Regarding varietal performance, the Radmira variety shows lower severity levels (1.40%) under intensive technology, followed by Belyana (1.48%) in 2022. Agros was the most effective, achieving a 1.69% severity level in 2023. The severity of the Radmira variety was reduced under intensive and high-intensive systems, exclusively in 2022. Our findings demonstrated that variety and cultivation technology are crucial in reducing disease prevalence. The increasing WPM severity in 2023 could be attributed to favorable environmental conditions for fungal colonization.

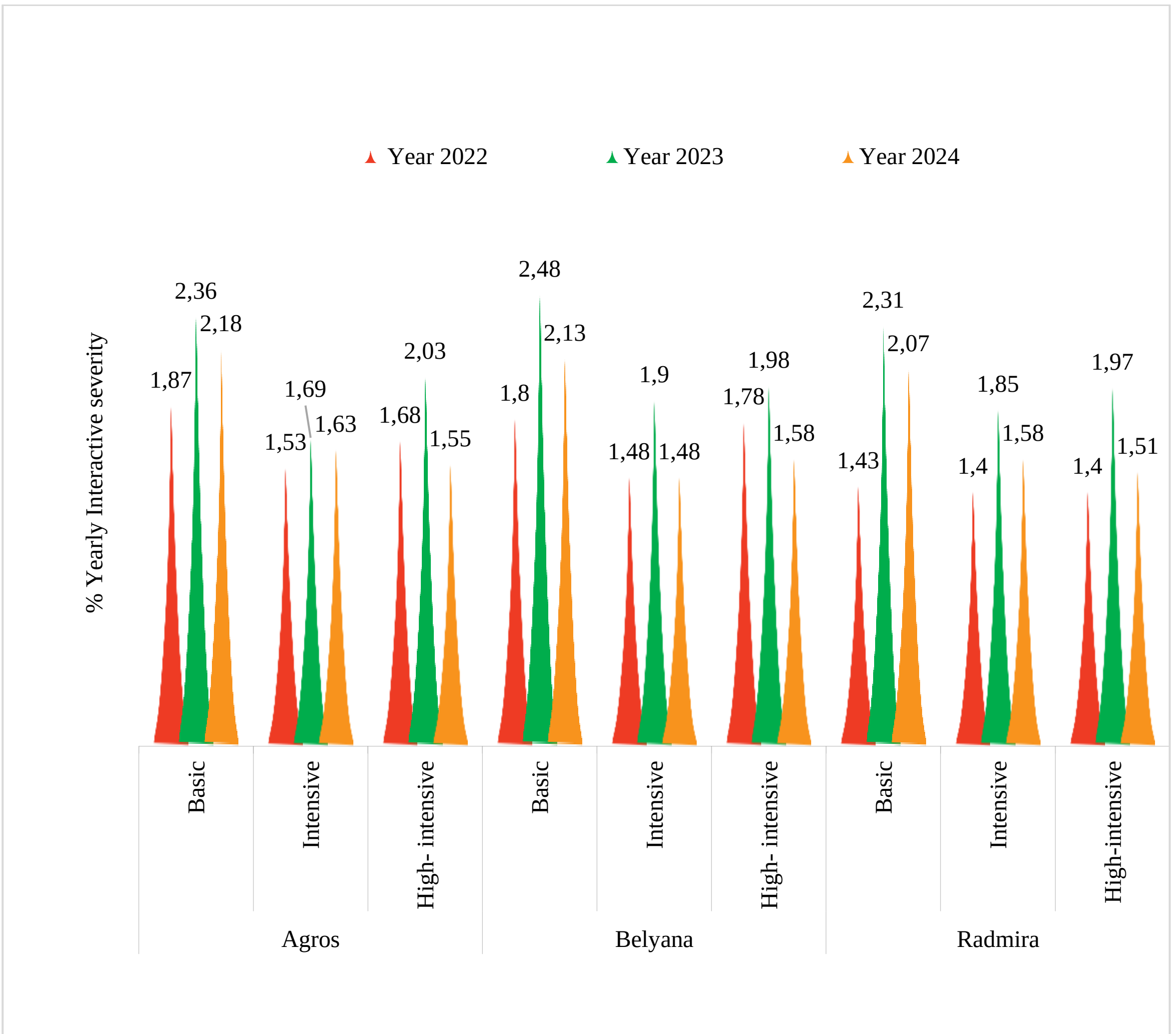


Figure 3.8. Interactive effect of varieties, cultivation technologies, and years affected by powdery mildew disease.

The efficacy of intensive and high-intensive cultivation techniques suggests that agronomic practices, including proper fertilization, timely fungicide application, and cultivar choice, could significantly manage and control WPM to an acceptable epidemiology threshold. The results align with current research on wheat powdery mildew, emphasizing the role of integrated agronomic practices, fungicide timing, and cultivar choice in mitigating the incidence and severity of the disease [75, 197, 302, 210, 206]. The study provides crucial insights for wheat producers and agronomists in selecting effective disease management strategies. Results underline the need for customized variety and input choices based on yield potential, local disease pressure, and yearly climatic conditions. Findings emphasize the importance of adopting intensive and high-intensive cultivation technologies to minimize powdery mildew infection, as shown in Figure 3.8.

4.4. The influence of three spring wheat varieties and three cultivation technologies on Fusarium head blight (FHB) incidence and severity

Fusarium head blight (FHB) is a significant economic disease caused by several species that infect wheat, leading to substantial yield losses (Figure 3.9).

Figure 3.9 Affected spikes by FHB disease in the experimental field studied.

In addition, the grains infected by FHB may be tainted with mycotoxins, especially trichothecenes, which are detrimental to human and animal health [303]. The Moscow region in central European Russia is an essential agricultural zone with favorable climatic conditions for growing spring and winter wheat. However, weather conditions like moderate temperatures, high humidity, and frequent rainfall during wheat flowering can create an ideal environment for spreading Fusarium species, the primary causal agents of FHB [304]. In recent years, the incidence and severity of FHB in the Moscow region have increased due to changing weather patterns associated with climate change, such as warmer springs and wetter summers [305, 303]. FHB poses a significant threat to grain quality, yield, and food safety due to its ability to produce mycotoxins such as deoxynivalenol (DON), which can contaminate grain and pose health risks to humans and livestock [304].

Table 3.13 shows the effect of spring wheat varieties and cultivation technologies on Fusarium head blight (FHB) incidence and severity from 2022 to 2024. Varietal differences were not significant ($P > 0.05$); however, cultivation technologies showed a statistically significant ($P < 0.001$) difference in controlling FHB: Agros and Belyana had similar average incidence (23.33%), while Radmira was slightly lower (21.67%); severity ranged narrowly from 1.89% (Radmira) to 2.03% (Agros). Basic technology recorded the highest incidence (30.25%) and severity (2.44%), whereas Intensive treatment was most effective, recording the lowest incidence rate (17.03%) and severity (1.79%). High-intensity cultivation technology showed intermediate results (21.05%) incidence and (1.83%) severity.

Year effects were also highly significant ($P < 0.001$): 2023 had the highest severity (2.26%) despite moderate incidence (20.06%), while 2024 showed higher incidence (24.26%) but lower severity (2.00%) (Table 3.13 and Figure 3.9). These results demonstrate that intensive management is critical for FHB suppression, even when varietal resistance was not very effective.

In analyzing the percentage reduction of FHB for variety and cultivation technology, Intensive technology reduces the disease incidence by 43.69% and severity by 26.54%, respectively. The varietal assessment shows that Belyana and Agros varieties reduce the incidence of FHB by (7.68%) for both varieties but exhibited different severity levels with Belyana recording the lowest severity of (4.06% and Agros (7.24%).

Agros and Belyana show the highest average incidence (23.33%). Although both varieties have similar incidence, they demonstrate different severity levels, with Agros scoring the highest (2.02%) and Belyana (1.96%). This could be traced to varietal phenotypic variations. Intensive technology proved to be the most effective in reducing disease pressure, resulting in the lowest incidence (17.03%) and severity (1.79%); this could be attributed to the cultivation techniques employed in the study.

The results highlight that cultivation technology had a more significant impact on FHB control than wheat variety, with Intensive technology being the most effective management method in reducing disease pressure. The results are in analogy with early research [303, 306, 122, 139, 140], indicating that FHB is a challenging condition to manage and highlighting the need to develop management methods aimed at mitigating losses attributed to FHB.

The study emphasizes the necessity of effective management of FHB, which cannot be achieved with a singular approach. Hence, FHB disease could be controlled by integrated disease management by mixing appropriate fungicides with resistant crop cultivars to diminish the inoculum in vulnerable crops. Wheat producers, other cereal producers, and breeders should adopt intensive cultivation technology, focusing on disease management strategies.

Table 3.13 – The effect of three spring wheat varieties and three cultivation technologies on the prevalence (incidence) and severity of Fusarium head blight (FHB)

Treatments	*Fusarium* head blight **disease incidence (%)**			**Three years Average**	**± (%) Reduction vs. Basic**	*Fusarium* head blight **disease severity (%)**			**Three years Average**	**± (%) Reduction vs. Basic**
	2022	**2023**	**2024**			**2022**	**2023**	**2024**		
Factor A: Cultivation Technology										
Basic	30.56	26.48	33.70	30.25	-	1.86	2.78	2.67	2.44	-
Intensive	19.44	13.70	17.96	17.03	43.69	1.44	2.30	1.63	1.79	26.54
High -Intensive	22.04	20.00	21.11	21.05	30.41	1.54	2.23	1.71	1.83	25.03
P-value	<.001***	<.001***	<.001***	-	-	0.013**	0.002**	<001***	-	-
LSD 5%	1.76	1.90	3.13	-	-	0.22	0.29	0.23	-	-
Standard error (A)	0.78	0.83	1.38	-	-	0.09	0.13	0.10	-	-
CV%	3.2	4.2	5.7	-	-	5.9	5.7	5.1	-	-
Factor B: Varieties										
Agros	24.81	22.22	22.96	23.33	7.68	1.75	2.24	2.08	2.02	7.24
Belyana	24.44	17.96	27.59	23.33	7.68	1.62	2.30	1.97	1.96	4.06
Radmira (Standard)	22.78	20.00	22.22	21.67	-	1.47	2.23	1.96	1.89	-
P-value	0.767ns	0.191ns	0.338ns	-	-	0.253ns	0.691ns	0.260ns	-	-
LSD 5%	8.01	5.21	9.52	-	-	0.40	0.24	0.19	-	-
Standard error (B)	3.53	2.30	4.20			0.17	0.10	0.08		
CV%	14.7	11.5	17.3	-	-	10.8	4.6	4.2	-	-

CV%= coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns=not significant, ns= not significant, * =significant, **=very significant, ***=highly significant.

4.4.1. The average influence of spring wheat varieties and cultivation technologies on Fusarium head blight disease means incidence as altered by critical growth stages of wheat 2022-2024

Evaluating FHB disease at critical growth stages is essential for disease management, yield protection, and food safety. The assessment of the disease-scoring process commences at three stages (Figure 3.10). These stages are essential for farmers because they involve decision-making, which helps farmers develop informed strategies to apply fungicides at the right time. By identifying when and where symptoms have occurred, farmers can prevent economic losses and ensure food safety. The analysis of the pooled data unraveled high variance P<0.001) when the FHB percentage incidence on the varieties was evaluated. The FHB percentage incidence scores indicate that at the heading/ flowering stage, all varieties show reduced incidence levels when cultivated with intensive technology; however, at this stage, the Radmira variety obtained the lowest percentage incidence score (9.44%), followed by the Belyana variety (10.00%). At the milk/dough stage, Belyana (16.67%) and Radmira (16.67%) had the lowest and similar FHB disease incidence levels, suggesting similar genetic traits in suppressing FHB incidence. At the final stage of evaluation, ripening, and maturity, the Belyana (23.33%) and Radmira (22.78%) varieties exhibited and maintained similar statistical trends, as shown in Figure 3.10. Therefore, the result suggests that genotypes primarily affected FHB incidence from reaching a critical, damaging stage. In determining the appropriate cultivation technologies for reducing FHB incidence in wheat varieties across different growth stages, it was discovered that intensive technology had the lowest incidence and severity levels across all stages and three varieties. Although intensive technology had the lowest percentage of incidences, high-intensive technology maintains a moderate incidence effect compared to basic technology across all growth stages and varieties (Figure 3.10). It can be concluded that intensive technology can control FHB disease infection if used during the initial phase of pathogenicity. The basic technology consistently shows high incidence scores across all varieties at each assessed growth stage, as shown in Figure 10.

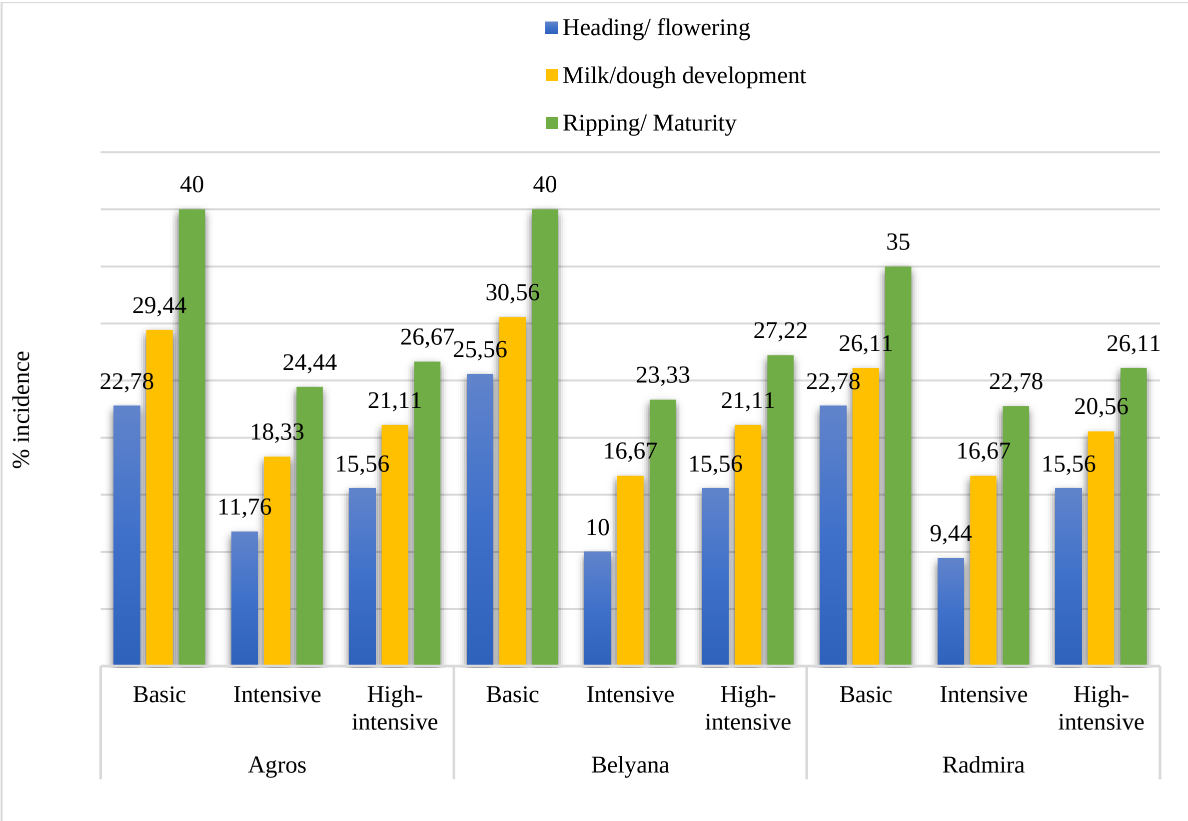


Figure 3.10**.** Average incidence of FHB disease as affected by Variety, technology, and growth stages.

The results suggest that intensive technology, including the Belyana and Radmira varieties, was more effective in reducing FHB incidence among all varieties. The intensive technology provides conditions that are not favorable for FHB progression and spread, as there is a high provision of inputs such as fertilizers and crop protection agents (products). The crop protection chemicals used limited the increase in FHB incidence across all growth stages. Similarly, [166, 304, 303, 306] opined that the treatment of fungicides is essential under specific environmental circumstances to protect wheat yield and ensure the production of high-quality food products from wheat. This research highlights the essence of exploring and devising novel approaches for predicting and detecting FHB outbreaks in cereals. This is essential to enhancing understanding of pertinent epidemiology factors and implementing knowledge-driven plant protection strategies. Concerning the interaction incidence effect, it is logical to state that the combined action of Belyana and Radmira varieties, along with intensive cultivation, significantly minimized the FHB outbreak. The cultivation practice (intensive technology) and varieties (Belyana and Radmira) could be strategic tools for wheat breeders, producers, and policymakers. They focus on increasing yield, mitigating wheat diseases, and providing more insight into managing and controlling FHB disease in wheat production.

4.4.2. Fusarium head blight (FHB) disease means severity as influenced by crucial growth stages, varieties, and cultivation technologies

Wheat and other cereal crops are susceptible to the fungal disease known as Fusarium head blight (FHB), which is caused by the fungus *F. graminearum*. This study assessed the effect of FHB severity using three varieties and three cultivation technologies across three crucial growth stages of wheat. The findings reveal distinct variations of FHB severity across wheat varieties, cultivation technologies, and growth stages. The first appearance of FHB disease symptoms was observed when the wheat was at the heading/flowering stage, with severity ranging from 1.23 to 2.34%, varying in variety and cultivation technology. At the heading/flowing stage, Agros (2.34%) under basic technology exhibited the highest FHB severity, while Belyana (1.23%), under intensive technology, showed the lowest FHB severity. The results are consistent with earlier research; the observed timing of FHB infection beginning during the flowering stage is consistent with the key infection phase for Fusarium species in wheat, as described by [209, 307, 308,159]. It is vital to note that FHB disease severity progresses over time. At ripening/maturity, the analysis revealed that Agros (2.63%) under basic technology had the highest disease incidence at the first appearance (heading/flowing). However, its disease progress was minimal, scoring 1.91% severity under intensive technology, and Radmira (1.86%) with the same intensive technology. Ghimire et al., [308], found similar disease progression patterns in their field experiments, and their observations of FHB progress under grain development stages align with our findings. In determining the influence of cultivation technologies on FHB disease severity, it was discovered that intensive and high-intensive cultivation technologies demonstrated protective effects by reducing FHB disease severity by 25-30% compared to basic technology at maturity. Notably, Radmira, under high-intensive cultivation technology, exhibited the lowest FHB disease severity (1.79%), as shown in Figure 3.11. Suggesting superior resistance when combined with intense management practices. Research conducted by [123] found that integrated management techniques using fungicides, optimal nutrition, and suitable crop rotations can lower the severity of FHB by 50-70%. This finding aligns with the protective impact of intensive technology practices, though at a lower range of these previously published values, our data indicate a 25-30% decrease under intensive practices.

The coherent pattern of high FHB severity under basic technology across all varieties and growth stages highlights the essence of best management practices in wheat production systems. The resistant mechanism exhibited by varieties under intensive and high-intensive technologies suggests the need for proper nutrition packages, timely and appropriate fungicide applications, and the use of hybrid varieties in this study. Varietal variations in the survey were evident, with Radmira showing overall resistance under intensive and high-intensive technology. The Belyana (1.84%) variety demonstrated resistance under the high-intensive technology, as shown in Figure 3.11, indicating strong genotype x environment interactions. The observed variations in FHB susceptibility align with the research conducted by [309], which states that wheat resistance to Fusarium infection may be influenced by genetics. The progressive increase in FHB disease severity during grain development highlights the disease's cumulative nature, as it continues to develop even after initial infection. Interestingly, the variance between intensive and high-intensive cultivation technologies was minimal for all varieties and growth stages. This suggests that the intensification of production systems provides adequate protection without necessitating maximum input levels. Nonetheless, this finding has important implications for cost-effective disease management strategies in commercial wheat production.

Wheat farmers and agricultural experts should consider this practical advice from these results. Farmers should prioritize intensive or high-intensive cultivation approaches to reduce the severity of FHB disease, especially for sensitive cultivars like Belyana. Prevention efforts must be initiated before the heading/flowering stage, when the first infection happens. The best method for controlling FHB is to use modern cultivation techniques combined with variety selection, especially Radmira. To establish safety criteria for each cultivation technique, future studies should examine the aspects of intensive cultivation methods that reduce FHB severity, as well as the mycotoxin buildup associated with the observed severity levels of FHB, as shown in Figure 3.11.

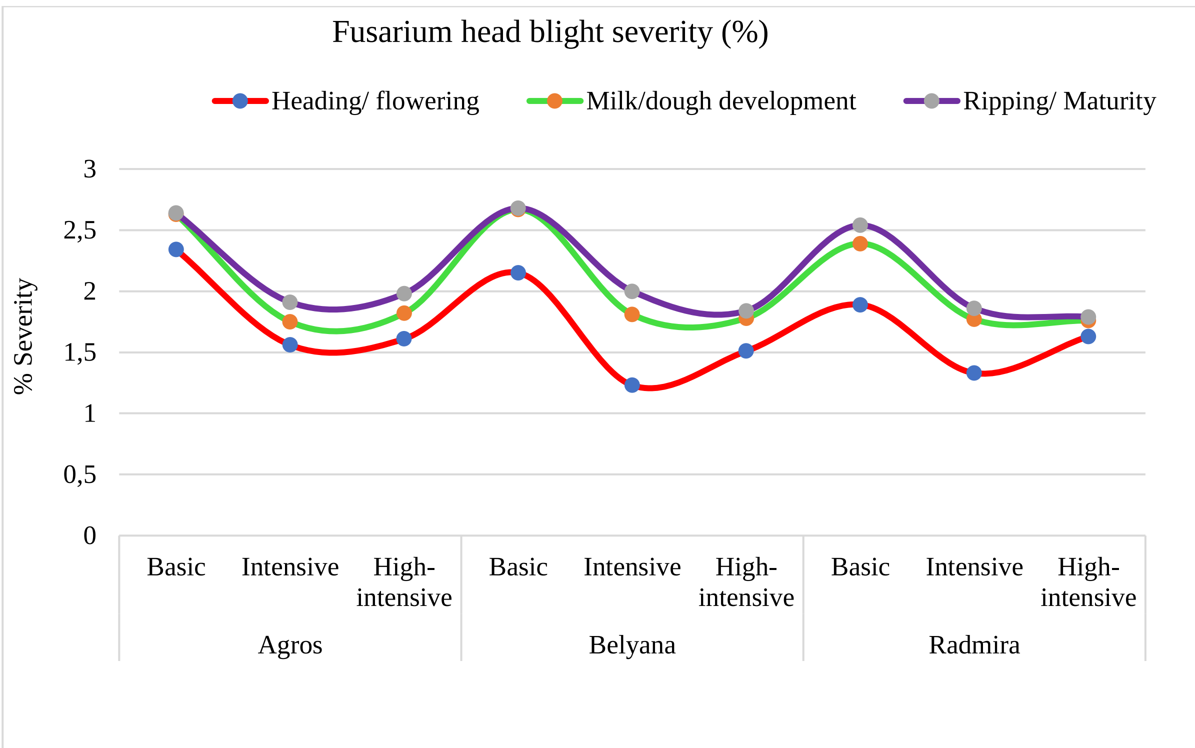


Figure 3.11. Average severity of Fusarium head blight (FHB) disease as affected by growth stages, varieties, and cultivation technologies.

4.4.3. The three-year mean severity of Fusarium head blotch (FHB) interaction across varieties and cultivation technologies 2022-2424

This section of the study evaluated the interactive effect of FHB overall percentage severity as affected by year, varieties, and cultivation technologies. The research outcome highlighted that Basic technology consistently demonstrated the highest FHB severity scores throughout all years and varieties, ranging from 1.60% to 2.99%, indicating significant disease pressure when this technology was employed. On the other hand, intensive and high-intensive technologies reduce FHB disease severity compared to basic technology, with percentage severity scoring 1.39% and 2.04% across years and varieties, demonstrating their efficacy in FHB disease management (Figure 3.12). Among the tested varieties, Radmira exhibited slightly better overall FHB resistance average severity (1.39%) with intensive technology, compared to Belyana (1.83%) and Agros (1.53%) in 2022, emphasizing genotypic variation in disease resistance mechanisms. The analysis of variance shows that the 2023 cropping year experienced more disease pressure across all varieties and cultivation technologies, with severity varying from 1.84% to 2.99%, suggesting favorable environmental conditions for disease development. However, the interactive effect of severity between varieties, cultivation technologies, and year significantly affected FHB management. A significant decrease in FHB percentage severity was observed with the Belyana variety when cultivated under intensive technology, compared to Basic technology, with the reduction in 2023 from 2.99% to 1.84%. This indicates that this variety is very responsive to intensive cultivation techniques used in this study. Although the Agros variety was most susceptible to FHB overall, it nonetheless showed significant improvement under intensive cultivation, with severity levels reducing from 2.84 to 1.64 in 2024. The preventive impact of intensive cultivation technology has been evident over the years, with cultivars showing a 25-40% reduction in FHB severity compared to basic cultivation, even during the high disease pressure year 2023. Notably, high-intensive cultivation did not consistently offer greater protection compared to intensive methods. It always exhibited additional protection beyond the intensive approach, with similar or occasionally higher severity scores, suggesting a potential threshold effect where increased inputs do not guarantee yield-proportional disease management benefits, as shown in Figure 3.13.

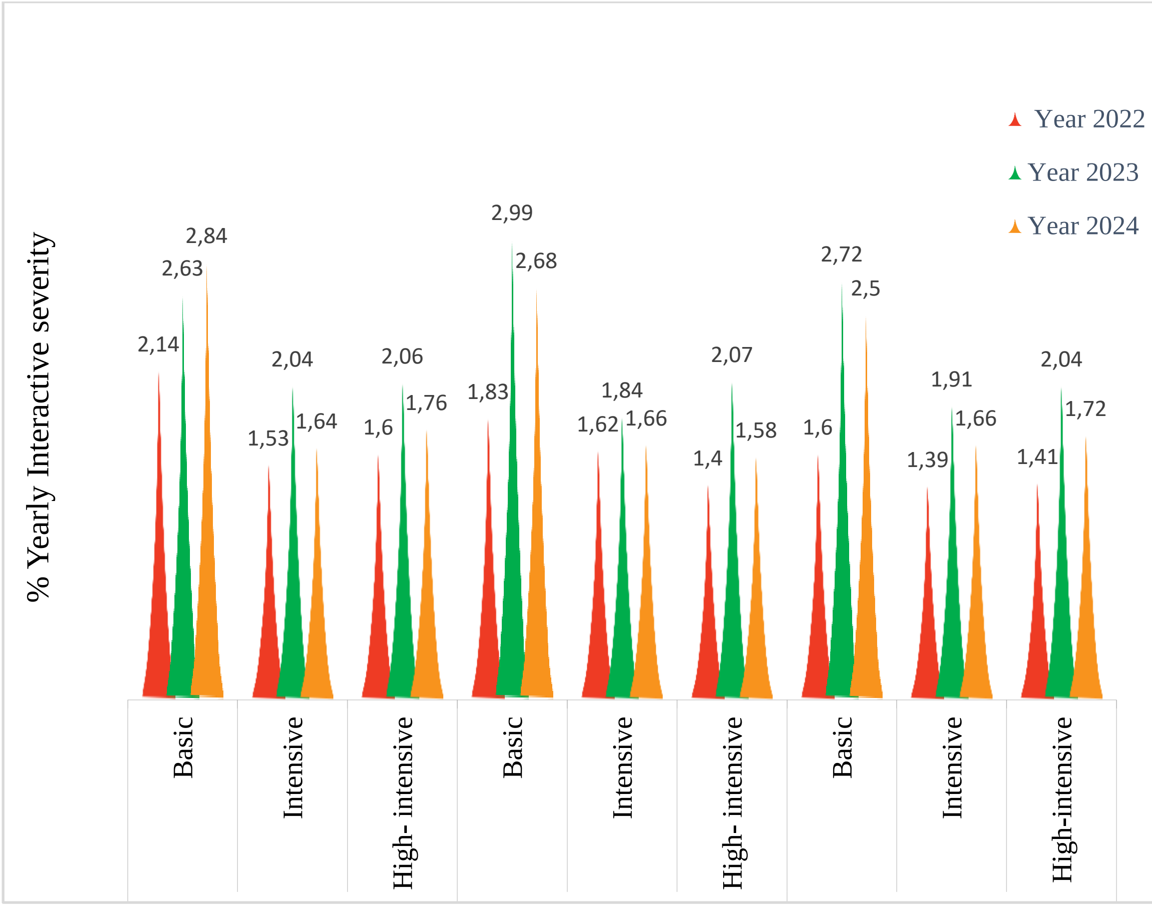


Figure 3.12. Three years of severity of Fusarium head blight (FHB) disease as affected by growth developmental stages on varieties and cultivation technologies.

Our study demonstrated that the efficacy of intensive cultivation technology is supported by research from [159, 308], which indicates that integrated management strategies reduce FHB severity in wheat production systems. The annual fluctuations in disease pressure validate existing research that illustrates the significant impact of climatic variables during flowering for FHB outbreaks. The varied responses of cultivars to cultivation technologies reflect results from genetic research, which indicates measurable resistance characteristics in diverse wheat genotypes. The extent of the decrease in FHB severity by improved cultivation technology (up to 46.8% reduction) is analogous to the effectiveness ranges documented in field studies evaluating integrated management strategies [308, 309, 159, 310].

For wheat growers and breeders, our results underscore the importance of employing intensive cultivation strategies to mitigate FHB risk, particularly during years with favorable weather conditions for FHB infection. Variety selection is crucial in FHB management strategies, with Belyana and Radmira exhibiting superior performance under optimal conditions. In addition, the results contribute to developing predictive models for FHB risk assessment by quantifying the interactive effects of variety, cultivation practice, and growing season. The study highlights the value of integrated approaches to FHB management rather than relying solely on genetic resistance or chemical control.

The three-year field study (2022–2024) in the Moscow region demonstrated that both spring wheat variety and cultivation technology significantly influence yield, grain quality, and disease resistance. Among the tested varieties, Belyana showed the most stable grain yield (4.64 t ha^{-1}) and strong resistance to Septoria leaf blotch (SLB) and powdery mildew. At the same time, Radmira excelled in quality traits, particularly gluten (25.15%) and protein (14.92%) content, making it suitable for bread-making. Agros exhibited moderate performance across traits but responded well to high-input systems. Intensive cultivation technology consistently outperformed basic and high-intensive approaches by suppressing key diseases SLB, powdery mildew, and Fusarium head blight (FHB). Disease pressure varied annually, with 2023 showing the highest incidence due to favorable climatic conditions for pathogens. The findings underscore that integrating genetically resilient varieties like Belyana and Radmira with intensive agronomic practices, including balanced fertilization, timely fungicide application, and crop protection, offers a sustainable strategy for maximizing productivity and grain quality while minimizing disease risk. This genotype × management interaction highlights the need for adaptive, region-specific wheat production systems that balance economic efficiency, environmental sustainability, and climate resilience in the face of increasing biotic and abiotic stresses.

5.0 CHAPTER FIVE ECONOMIC PARAMETER ESTIMATES OF SPRING WHEAT VARIETIES UNDER DIFFERENT CULTIVATION TECHNOLOGIES (2022–2024)

5.1. The impact of the different cultivation technologies on the economic parameter estimates of two novel spring wheat varieties (Agros and Belyana) and one landrace (Radmira), and Cultivation technologies (Basic, Intensive, and High-intensive)

The study investigated the influence and interactive effects of varieties and cultivation technologies on the fourteen (14) economic parameter estimates of three spring wheat varieties over three cropping seasons (2022 - 2024). The results revealed significant effects of these varieties and cultivation technologies on grain yield (GY) and agronomic efficiency of Nitrogen (AEN), Agronomic Efficiency of Phosphorus (AEP), Agronomic Efficiency of Potassium (AEK), the Partial factor productivity of Nitrogen (PFPN), Phosphorus (PFPP), Potassium (PFPK), gross return over control (GRIOC), grain yield value (GYV), marginal returns (MR), net returns (NR), and the value-cost ratio (VCR), breakeven point (BEP) and payback period (PBP).

5.2 Agronomic and Nutrient Use Efficiency Indicators

5.2.1. Agroeconomic estimates of spring wheat varieties and cultivation technologies of grain yield (GY) and agronomic efficiency of nitrogen (AE_N)

2022-2024

Analysis of variance confirmed that grain yield (GY) was significantly influenced by both spring wheat variety and cultivation technology across the three-year trial (2022–2024), with highly significant effects in 2023 and 2024 ($P < 0.001$) and a notable difference in 2022 (Table 3.14). Yield performance varied annually among varieties: Belyana achieved the highest yield in 2022 (4.84 t ha^{-1}), Radmira led in 2023 (5.07 t ha^{-1}), and Agros peaked in 2024 (4.95 t ha^{-1}). Over the trial period, the novel varieties outperformed the Standard Radmira. Belyana (4.64 t ha^{-1}) and Agros (4.51 t ha^{-1}), surpassing Radmira (4.44 t ha^{-1})—highlighting their potential for yield improvement in modern wheat systems [3.14].

Table 3.14 – Agroeconomic estimates of wheat varieties and cultivation technologies of Grain yield (GY) and Agronomic Efficiency of Nitrogen (AE_N) of three spring wheat.

Parameters/ Treatments	GY- t ha^{-1}			AE_N - kg kg^{-1} N		
	2022	2023	2024	2022	2023	2024
Factor A: Cultivation Technology						
Basic	3.64	4.05	4.27	0.00	0.00	0.00
Intensive	4.86	4.46	4.76	20.20	6.94	8.17
High -intensive	5.01	4.78	4.94	15.20	8.16	7.37
P-value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
$LSD_{5\%}$	0.14	0.14	0.08	4.56	1.71	1.26
Standard error (A)	0.06	0.06	0.04	2.01	0.75	0.56
CV%	1.4	1.4	0.8	17.1	15.0	10.8
Factor B: Varieties						
Agros	4.78	3.80	4.95	10.20	7.40	4.78
Belyana	4.84	4.42	4.66	12.20	3.62	6.63
Radmira	3.89	5.07	4.37	12.90	4.09	4.13
P-value	0.007**	<.001***	<.001***	0.620ns	<.001***	0.003*
$LSD_{5\%}$	0.22	0.17	0.01	7.57	0.79	0.85
Standard error (B)	0.10	0.08	0.01	3.34	0.35	0.37
CV%	2.2	1.7	1.0	28.3	6.9	7.2

GY=grain yield, AEN=agronomic efficiency of nitrogen, CV=coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

Cultivation technology had a profound impact: High-Intensive management consistently recorded the highest yields (5.01, 4.78, and 4.94 t ha^{-1}) over the three years, followed closely by Intensive (4.86, 4.46, 4.76 t ha^{-1}), while Basic technology remained the lowest (3.64–4.27 t ha^{-1}). The Intensive system demonstrated superior Agronomic Efficiency of Nitrogen (AEN), averaging 11.78 kg grain per kg N compared to High-Intensive (10.24) and Basic (0.00), indicating better nitrogen use efficiency. Although Radmira showed the highest AEN in 2022 (12.90), Belyana recorded the most excellent 3-year average (7.49), slightly ahead of Agros (7.46) (Table 3.14). These findings underscore that Intensive technology optimizes both productivity and resource efficiency, aligning with prior studies on integrated agronomic systems [274, 312, 313] and offering a sustainable pathway for wheat intensification.

5.2.2. Interactive effect of varieties and cultivation technologies on grain yield (GY), and the agronomic efficiency of nitrogen (AEN) of three spring wheat (2022-2024)

The interactive effect of spring wheat varieties and cultivation technologies across all three years shows a statistically significant impact on wheat grain yield ($P \leq 0.027$) in Table 3.15. In 2022, Agros under High-Intensive management achieved the highest grain yield (5.40 t ha^{-1}), closely followed by Belyana (5.31 t ha^{-1}), while Radmira under Basic technology recorded the lowest (2.96 t ha^{-1}). In 2023, Radmira under Intensive technology obtained the highest grain yield of (5.3 t ha^{-1}), which was statistically similar to Belyana (4.7 t ha ^{1} under the same intensive technology. In contrast, Agros under Basic technology yielded the least (3.24 t ha^{-1}). However, in 2024, Agros led with the highest grain yield of (5.22 t ha^{-1}), under the High-Intensive system, followed by Belyana (5.13 t ha^{-1}), while Radmira under Basic remained the lowest (4.08 t ha^{-1}).

Over the trial, Belyana achieved the highest mean GY (4.46 t ha^{-1}) under High-Intensive management, followed by Agros (4.51t ha^{-1}); Radmira reached (4.44 t ha^{-1}) under the Intensive systems. Overall, high-intensive technology shows a better yield performance compared to intensive and basic technology. This response might be due to the split application of nitrogen during tillering and stem elongation, a practice known to enhance nitrogen use efficiency and reduce leaching [314, 315].

Agronomic Efficiency of Nitrogen (AEN) also varies markedly. Radmira under Intensive technology showed the highest AEN in 2022 (23.83 kg grain kg^{-1} N), while Agros (11.78) in 2023 and Belyana (10.89) led in 2024, both under High-Intensive management. On average, Radmira achieved the greatest AEN (12.72) under Intensive input, outperforming Belyana (11.63) and Agros (10.98). This indicates superior nitrogen conversion efficiency, likely due to balanced N supply, avoiding lodging or losses from over-application (Table 3.15).

Table 3.15 - Interactive effect of three varieties and cultivation technologies on grain yield (GY), and agronomic efficiency of nitrogen (AE_N) spring wheat (2022-2024).

Parameters	GY- t ha^{-1}			AE_N - kg kg^{-1} N		
	2022	2023	2024	2022	2023	2024
Treatment interactions						
Agros× Basic	4.01	3.2	4.59	0.00	0.00	0.00
Agros× Intensive	4.92	4.3	5.03	15.17	10.44	7.33
Agros× H. Intensive	5.40	3.9	5.22	15.45	11.78	7.00
Belyana× Basic	3.96	4.1	4.15	0.00	0.00	0.00
Belyana× Intensive	5.26	4.7	4.69	7,22	4.22	9.00
Belyana× H. Intensive	5.31	4.4	5.13	5.00	6.63	10.89
Radmira× Basic	2.96	4.8	4.08	0.00	0.00	0.00
Radmira× Intensive	4.39	5.3	4.57	23.83	6.17	8.17
Radmira× H. Intensive	4.31	5.1	4.46	15.00	6.11	4.22
P-value-	0.027^{*}	$<.001^{***}$	$<.001^{***}$	0.596^{ns}	$<.001^{***}$	$<.001^{***}$
LSD $_{5\%}$	0.31	0.18	0.08	8.81	1.71	1.42
Standard error (AxB)	0.23	0.04	0.05	5.44	0.59	0.76
CV (%)	5.0	1.0	1.0	46.1	11.6	14.6

GY= grain yield, AEN=agronomic efficiency of nitrogen, CV=coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant

These results confirm that optimal pairing of high-performing varieties (Agros, Belyana) with High-Intensive systems maximizes yield, while Radmira offers high nitrogen-use efficiency under Intensive management, as shown in Table 3.15. This supports adaptive, resource-smart wheat production [318, 319], where varietal traits and input strategies are aligned for productivity, profitability, and environmental sustainability [262, 311, 316, 317].

5.2.3. The agroeconomic estimates of varieties and cultivation technologies on the Agronomic Efficiency of Potassium (AE_K), and Agronomic Efficiency of Phosphorus (AE_P)

Analysis of variance revealed no significant differences among varieties for Agronomic Efficiency of Potassium (AEK) in 2022 ($P = 0.642$), but highly significant effects emerged in 2023 and 2024 ($P < 0.001$; Table 3.16). Radmira recorded the highest AEK in 2022 (6.98 kg grain kg^{-1} K), while Agros was the lowest (5.62). However, Agros led in 2023 (4.09), and Belyana in 2024 (3.68), while Radmira dropped to 2.20, reaching its lowest that year. Over the three years, Belyana and Agros showed the highest mean AEK (4.11 each), slightly outperforming Radmira (3.81), indicating a stronger potassium-use efficiency in the modern varieties (Table 3.16). Assessing for cultivation effectiveness, intensive technology surpasses high-intensive technology by recording the highest agronomic efficiency of potassium from 2022 to 2024.

A similar pattern was observed for Agronomic Efficiency of Phosphorus (AEP). Radmira led in 2022 (12.90 kg grain kg^{-1} P), Agros in 2023 (7.40), and Belyana in 2024 (6.63). On average, Belyana achieved the highest AEP (7.49), followed closely by Agros (7.46) and Radmira (7.06). Notably, Intensive technology delivered the highest mean AEP (20.20), while High-Intensive gave the AEK (15.2), underscoring the importance of tailored nutrient management (Table 3.16).

These results highlight differential genotypic responses to potassium and phosphorus under varying input intensities, which is consistent with findings by [311, 317]. Although all varieties responded similarly to nitrogen (as reflected in comparable grain yields per unit N), their efficiency in utilizing K and P varied significantly by year and management practices. For optimal productivity and resource use efficiency, Belyana and Agros are best paired with High-Intensive or Intensive systems. These systems enhance early-season nutrient uptake, support sustained growth, and improve long-term yield stability, which are key considerations for sustainable wheat intensification in variable environments Table 3.16.

Table 3.16 - Agroeconomic estimates of three varieties and cultivation technologies on the Agronomic Efficiency of Potassium (AE_K), and Phosphorus (AE_P) of spring wheat.

Parameters/ Treatments	AE_K -Kg Kg^{-1} K			AE_P - Kg Kg^{-1} P		
	2022	2023	2024	2022	2023	2024
Factor A : Cultivation Technology						
Basic	0.00	0.00	0.00	0.00	0.00	0.00
Intensive	10.12	4.90	4.08	20.20	6.94	8.71
High -intensive	9.09	3.47	4.42	15.2	8.16	7.37
P-value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
LSD $_{5\%}$	2.44	0.94	0.64	4.56	1.71	1.26
Standard error (A)	1.08	0.42	0.28	2.01	0.75	0.56
CV%	16.8	15.1	10.0	17.1	15.0	10.8
Factor B: Varieties						
Agros	5.62	4.09	2.62	10.20	7.40	4.78
Belyana	6.61	2.03	3.68	12.20	3.62	6.63
Radmira	6.98	2.25	2.20	12.90	4.09	4.13
P-value	0.642ns	<.001***	0.001**	0.620ns	<.001***	0.003*
LSD $_{5\%}$	3.91	0.43	0.42	7.57	0.79	0.85
Standard error (B)	1.72	0.19	0.18	3.34	0.35	0.37
CV%	26.9	6.8	6.5	28.3	6.9	7.2

AEK=agronomic efficiency of potassium, AEP=agronomic efficiency of phosphorus, CV=coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

5.2.4. The Interaction between spring wheat varieties and cultivation technologies on Agronomic Efficiency of Potassium (AEK) and Phosphorus (AEP)

Statistical analysis revealed a highly significant interaction ($P < 0.001$) between spring wheat varieties and cultivation technologies for both Agronomic Efficiency of Potassium (AEK) and Phosphorus (AEP) in 2023 and 2024, though not in 2022 ($P > 0.60$; Table 3.17). The highest AEK values occurred under advanced management: Radmira with Intensive technology in 2022 (11.93 kg grain kg^{-1} K), Agros with High-Intensive in 2023 (7.04), and Belyana with High-Intensive in 2024 (6.53). Similarly, AEP peaked with Radmira × Intensive in 2022 (23.80), Agros × High-Intensive in 2023 (11.74), and Belyana × High-Intensive in 2024 (10.89) (Table 3.17).

Table 3.17 - Interactive effect of agroeconomic estimates of three varieties and cultivation technologies on the Agronomic Efficiency of Potassium (AE_K), and Phosphorus (AE_P) of spring wheat.

Parameters	AE_K -Kg Kg^{-1} K			AE_P - Kg Kg^{-1} P		
	2022	2023	2024	2022	2023	2024
Treatment interactions						
Agros× Basic	0.00	0.00	0.00	0.00	0.00	0.00
Agros× Intensive	7.60	5.22	3.67	15.20	10.44	7.33
Agros× H. Intensive	9.27	7.04	4.20	15.50	11.74	7.00
Belyana× Basic	0.00	0.00	0.00	0.00	0.00	0.00
Belyana× Intensive	10.83	2.11	4.50	21.70	4.22	9.00
Belyana× H. Intensive	9.00	3.98	6.53	15.00	6.63	10.89
Radmira× Basic	0.00	0.00	0.00	0.00	0.00	0.00
Radmira× Intensive	11.93	3.08	4.08	23.80	6.17	8.17
Radmira× H. Intensive	9.00	3.67	2.53	15.00	6.11	4.22
P-value-	0.602^{ns}	$<.001^{***}$	$<.001^{***}$	0.596^{ns}	$<.001^{***}$	$<.001^{***}$
LSD 5%	4.54	0.95	0.72	8.81	1.71	1.42
Standard error (AxB)	2.75	0.32	0.38	5.44	0.59	0.76
CV (%)	42.9	11.4	13.6	46.1	11.6	14.6

AEK=agronomic efficiency of potassium, AEP=agronomic efficiency of phosphorus, CV=coefficients of variation, LSD 5%= Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

Over the three years, Agros under High-Intensive management achieved the mean AEK (6.84), demonstrating distinct nutrient-use efficiency genotypes, while Radmira under

Intensive cultivation recorded the mean AEP (6.36), and Belyana recorded the lowest AEK efficiency (5.81). A similar trend was observed with the trait APK, where Radmira (23.80) led under intensive technology in 2022, Agros (11.74) under high intensive technology in 2023, and Belyana (10.89) led in 2024 under high intensive technology, attaining the highest nutrient use efficiency. Notably, all varieties performed poorly under Basic technology (AEK and AEP = 0.00), confirming that nutrient efficiency is contingent on adequate input levels (Table 3.17).

These results demonstrate strong genotype × management interactions, where Agros and Belyana show consistent responsiveness to high nitrogen, phosphorus, and potassium inputs, while Radmira excels in phosphorus conversion under Intensive systems. This differential response underscores the need for precision pairing of varieties with tailored nutrient regimes to maximize efficiency and yield.

The findings align with [321, 322], who emphasize that matching cultivars to production systems enhances food security while reducing fertilizer overuse and environmental impact. Future research should explore the physiological and root-architectural traits driving these efficiencies and assess their long-term effects on soil health and yield stability—key pillars of sustainable intensification in spring wheat systems.

5.2.5. The influence of varieties and cultivation technologies on the Partial factor productivity of Nitrogen (PFPN) and Potassium (PFPK)used in three spring wheat varieties

Table 3.18 presents Partial Factor Productivity (PFP) of nitrogen (PFPN) and potassium (PFPK), key indicators of economic efficiency in wheat production, measuring grain output per unit of nutrient applied. Contrary to yield-focused metrics, PFP reveals diminishing returns under high-input systems. In 2022, Basic technology achieved the highest mean of PFPN (121.40, 134.93, and 142.44 kg grain kg^{-1} N), indicating its ability to convert nutrients for efficient crop uptake. However, intensive technology from 2022 to 204 recording (80.90, 74.41, and 79.39kg grain kg^{-1} N) outperformed high-intensive technology.

Our findings recorded that PFPK was high with basic technology, followed by intensive technology, as shown in Table 3.18. This inverse relationship between input intensity and PFPK and PFPN confirms that excessive fertilization in advanced systems exceeds crop uptake capacity, reducing economic efficiency, a pattern consistent with findings by Wan et al. [323] and Saquee et al. [324].

Varietal differences with PFPN and PFPP were statistically insignificant (P<0.001) across all three years. Belyana shows a higher average (PFPN: 92.90; PFPK: 41.08 kg grains Kg-1 N and P) in 2022. In 2023, Radmira (PFPN: 101.19; PFPK: 43.74 kg grains Kg-1 N and P), and in 2024, Agros attained the highest nutrient use efficiency of (PFPN: 98.28; PFPK: 42.57 kg grains Kg-1 N and P). However, year-to-year variability was substantial; for example, Radmira PFPN surged to 101.19 in 2023, highlighting the influence of environmental conditions and management practices over genetics, as findings agree with [321].

Table 3.18 - Agroeconomic estimates of varieties and cultivation technologies on the Partial factor productivity of Nitrogen (PFPN) and Potassium (PFPK) used in three spring wheat varieties

Parameters/ Treatments	PFP_N -Kg grains Kg^{-1} N			PFP_K -Kg grains Kg^{-1}K		
	2022	2023	2024	2022	2023	2024
Factor A : Cultivation Technology						
Basic	121.40	134.93	142.44	40.49	44.98	47.48
Intensive	80.90	74.41	79.39	40.49	37.20	39.70
High -intensive	55.60	53.14	54.85	33.39	31.88	32.91
P-value	<.001***	<.001***	<.001***	0.002**	<.001***	<.001***
$LSD_{5\%}$	5.45	3.48	2.59	2.59	1.28	0.88
Standard error (A)	2.40	1.54	1.14	1.14	0.56	0.39
CV%	2.8	1.8	1.2	3.0	1.5	1.0
Factor B: Varieties						
Agros	91.90	73.46	98.28	40.53	32.32	42.57
Belyana	92.90	87.82	91.17	41.08	38.00	39.80

Radmira	73.20	101.19	87.24	32.76	43.74	37.72
P-value	0.003*	<.001***	<.001***	0.005**	<.001***	<.001***
LSD $_{5\%}$	7.37	3.87	0.17	3.59	1.56	0.07
Standard error (B)	3.25	1.71	0.08	1.59	0.69	0.03
CV%	3.8	2.0	0.1	4.2	1.8	1.0

PFPN=partial factor productivity of nitrogen, PFPK=partial factor productivity of potassium, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

These results challenge the assumption that higher inputs guarantee better returns. Instead, they support resource-optimized strategies: Basic technology, despite lower yields, delivers superior economic efficiency per unit of fertilizer. This has critical implications for policy and extension services, which should promote balanced, context-specific fertilization rather than blanket high-input recommendations. Future research should evaluate the long-term impacts on soil health and conduct economic analyses under fluctuating input and grain prices to assess the resilience of these systems in dynamic markets, as shown in Table 3.18.

5.2.6. Interactive impacts of variety and cultivation technologies on the Partial factor productivity of Nitrogen (PFPN) and Potassium (PFPK) on three spring wheat varieties

Since Partial Factor Productivity (PFP) is a critical metric for evaluating the economic sustainability of cropping systems, Table 3.19 examines the interactive effects of three spring wheat varieties and cultivation technologies on PFP of nitrogen (PFPN) and potassium (PFPK), which are essential. The analysis confirms that Basic technology consistently delivered the highest PFP values across all varieties. In 2022, Agros × Basic achieved the peak PFPN (133.67 kg grain kg^{-1} N) and PFPK (44.57 kg grain kg^{-1} K), attaining the highest values among all treatment combinations. This highlights Agros' superior ability to convert limited nutrient inputs into grain yield, likely due to favorable genetic traits for resource-use efficiency [325, 326].

Belyana also performed well under Basic management (PFPN: 132.00; PFPK:45.93kg grain kg^{-1} N and K), aligning with its high yield potential (4.69 t/ha) under Intensive systems as shown in 3.7.

The interaction effects reveal that neither variety or technology alone determines profitability; optimal returns depend on strategic pairing. While Intensive and High-Intensive systems boost yields, they drastically reduce PFP—e.g., Belyana's PFPN drops from 136.04 (Basic) to 57.00 (High-Intensive)—reflecting diminishing returns from excessive inputs [323, 328].

These findings support a shift toward sustainable intensification: prioritizing input-use efficiency over input volume. For small- and medium-scale farmers, Belyana under Basic technology offers a resilient, low-cost, and eco-efficient option. Policymakers should align subsidies and extension services with such synergistic variety–management combinations to enhance farm profitability while reducing environmental footprints—core tenets of precision and sustainable agriculture [327].

Table 3.19 - Interactive effect of varieties and cultivation technologies on the Partial factor productivity of Nitrogen (PFPN) and Potassium (PFPK) used in three spring wheat varieties

Parameters	PFP_N -Kg grains Kg^{-1} N			PFP_K -Kg grains Kg^{-1}K		
	2022	2023	2024	2022	2023	2024
Treatment interactions						
Agros× Basic	133.67	108.11	153.00	44.57	36.04	51.00
Agros× Intensive	82.00	64.50	83.83	41.03	32.25	41.92
Agros× H. Intensive	60.00	47.78	58.00	36.00	28.67	34.80
Belyana× Basic	132.00	137.78	138.33	44.00	45.93	46.11
Belyana× Intensive	87.70	73.11	78.17	43.83	36.55	39.08
Belyana× H. Intensive	59.00	52.26	57.00	35.40	31.53	34.20
Radmira× Basic	98.70	158.89	136.00	32.90	52.96	45.33
Radmira× Intensive	73.20	85.61	76.17	36.60	42.81	38.08
Radmira× H. Intensive	47.89	59.08	49.56	28.77	35.45	29.73
P-value-	0.020^{*}	$<.001^{***}$	$<.001^{***}$	0.303^{ns}	$<.001^{***}$	$<.001^{***}$

LSD $_{5\%}$	9.14	4.46	2.53	4.44	1.71	0.88
Standard error (AxB)	5.77	1.53	0.84	2.82	0.47	0.39
CV (%)	6.7	1.7	0.9	7.4	1.2	1.0

PFPN=partial factor productivity of nitrogen, PFPK=partial factor productivity of potassium, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

5.2.7. The influence of varieties and cultivation technologies on Partial factor productivity of Phosphorus (PFPP) and cost that varies (CostV)

ANOVA revealed that cultivation technology had a highly significant effect ($P < 0.001$) on Partial Factor Productivity of Phosphorus (PFPP) in spring wheat (Table 3.20). PFPP declined sharply with increasing input intensity: Basic technology achieved the highest PFPP (99.10 kg grain kg^{-1} P), followed by Intensive (80.90), and High-Intensive (55.60), demonstrating clear diminishing returns from excessive phosphorus and associated inputs. This trend aligns with global evidence that over-application of fertilizers reduces nutrient-use efficiency and economic returns [323, 329].

Among varieties, Belyana was able to utilize phosphorus nutrients effectively, recording the highest average PFPP (80.70 kg grain kg^{-1} P), slightly outperforming Agros (81.90 kg grain kg^{-1} P) and Radmira (65.00 kg grain kg^{-1} P) in 2022. In 2023, Radmira increased its nutrient use efficiency and recorded (87.95kg grain kg^{-1} P), indicating superior phosphorus conversion efficiency, which could be related to genetic differences in root architecture or uptake mechanisms, as this result agrees with previous studies [321, 322]. On average, the analysis demonstrated that Belyana exhibited high Phosphorus use efficiency, which was converted into a high grain yield. This is evident in its increased yield, demonstrating strong genotype × nutrient interactions.

These findings confirm that higher input intensity does not guarantee higher profitability. Instead, Belyana under Basic or low-input systems offers the best balance of nutrient-use efficiency, yield stability, and cost-effectiveness. For sustainable wheat production, especially on resource-limited farms, the priority should shift from maximizing inputs to optimizing input-use efficiency through strategic variety–management pairing. Policymakers and extension services should promote such integrated approaches to enhance farm resilience, reduce environmental impact, and improve long-term profitability.

The variable production cost (CostV) increases with intensification, with basic systems averaging 21,303 RUB/ha. In comparison, Intensive technology costs 24,215 RUB/ha, and High-Intensive systems cost 25,345.33 RUB/ha, respectively, primarily due to higher fertilizer and plant protection inputs.

Table 3.20 - Agroeconomic estimates of varieties and cultivation technologies on Partial factor productivity of Phosphorus (PFPP) and Cost that varies (CostV) in three spring wheat.

Parameters/ Treatments	**PFP_P -Kg grains Kg^{-1} P**			**CostV (Rub.)**		
	2022	**2023**	**2024**	**2022**	**2023**	**2024**
Factor A: Cultivation Technology						
Basic	91.10	101.19	106.83	20,980.00	21,450.00	21,479.00
Intensive	80.90	74.41	79.39	23,600.00	24,503.00	24,542.00
High -intensive	55.60	53.14	54.85	24,713.00	25,650.00	25,700.00
P-value	<.001***	<.001***	<.001***	-	-	-
$LSD_{5\%}$	5.00	101.19	1.97	-	-	-
Standard error (A)	2.21	1.19	0.87	-	-	-
CV%	2.9	1.6	1.1	-	-	-
Factor B: Varieties						
Agros	80.70	64.45	85.53	23,097.67	23,867.67	23,907.00
Belyana	81.90	76.33	79.64	23,097.67	23,867.67	23,907.00
Radmira	65.00	87.95	75.91	23,097.67	23,867.67	23,907.00
P-value	0.005**	<.001***	<.001***	-	-	-
$LSD_{5\%}$	7.23	3.24	0.12	-	-	-
Standard error (B)	3.19	1.43	0.05	-	-	-
CV%	4.2	1.9	0.1	-	-	-

PFPP=partial factor productivity of phosphorus, CostV=cost that varies, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns=not significant, * =significant, **=very significant, ***=highly significant.

5.2.8. Interactive impacts of variety and cultivation technologies on partial factor productivity of phosphorus (PFPP)

Table 3.21 highlights the interactive effects of spring wheat varieties and cultivation technologies on Partial Factor Productivity of Phosphorus (PFPP) across 2022–2024. While the interaction was not significant in 2022 (P = 0.128), it became statistically significant in 2023 and 2024 (P < 0.001), reflecting strong year-by-year interactive responses to cultivation technology and genetics.

On average, the Basic technology interacted better with all varieties, achieving their highest PFPP, with Belyana attaining the highest PFPP at 102.03 kg grain kg^{-1} P, followed closely by Agros (98.71kg grain kg^{-1} P). Agros × Basic maintained the most stable and efficient performance (PFPP: 100.03 in 2022 and 114.75 in 2024 kg grain kg^{-1} P), slightly outperforming Belyana × Basic (99.00 in 2022 and 103.75 in 2023 kg grain kg^{-1} P). Radmira × Basic (119.17 kg grain kg^{-1} P) showed the highest in 2023 PFPP. In contrast, High-Intensive systems drastically reduced PFPP across all varieties.

Table 3.21 - Interactive effect of varieties and cultivation technologies on the partial factor productivity of Phosphorus and variable cost in spring wheat

Parameters	PFP_P -Kg grains Kg^{-1} P			CostV (Rub.)		
	2022	2023	2024	2022	2023	2024
Treatment interactions						
Agros× Basic	100.30	81.08	114.75	20,980.00	21,450.00	21,479
Agros× Intensive	82.00	64.50	83.83	23,600.00	24,503.00	24,542
Agros× H. Intensive	60.00	47.78	58.00	24,713.00	25,650.00	25,700
Belyana× Basic	99.00	103.33	103.75	20,980.00	21,450.00	21,479
Belyana× Intensive	87.70	73.11	78.17	23,600.00	24,503.00	24,542
Belyana× H. Intensive	59.00	52.5	57.00	24,713.00	25,650.00	25,700
Radmira× Basic	74.00	119.17	102.00	20,980.00	21,450.00	21,479
Radmira× Intensive	73.20	85.61	76.17	23,600.00	24,503.00	24,542
Radmira× H. Intensive	47.90	59.08	49.56	24,713.00	25,650.00	25,700
P-value-	0.128^{ns}	$<.001^{***}$	$<.001^{***}$	-	-	-
$LSD_{5\%}$	8.81	3.61	1.94	-	-	-
Standard error (AxB)	5.57	1.10	0.77	-	-	-

CV (%)	7.3	1.4	1.0	-	-	-

PFPP=partial factor productivity of phosphorus, PFPP=partial factor productivity of phosphorus, CostV=cost that varies, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns=not significant, * =significant, **=very significant, ***=highly significant.

Notably, CostV varied across varieties within each technology, confirming that input costs are driven by management. However, economic efficiency, measured as output per unit cost, varied widely.

These results reinforce that maximizing inputs does not maximize efficiency. Instead, Belyana, when paired with Basic or low-input systems, offers the best trade-off in phosphorus-use efficiency, making it a valuable technique for small- and medium-scale farms Table 3.12. This reflects sustainable intensification: maximizing resource efficiency instead of increasing inputs [321, 323, 329]. For policymakers, the findings support redirecting subsidies and advisory services toward cost-effective, low-input systems matched with efficient cultivars, enhancing both farm profitability and environmental sustainability.

5.3. Financial Performance and Return Metrics

5.3.1. Influence of varieties and cultivation technologies on the increase in gross return over control (GR_{IOC}) and grain yield value (GY_V) of three spring wheat varieties

Table 3.22 shows the effects of spring wheat varieties and cultivation technologies on Grain Yield Value (GYV) and Gross Return Increase Over Control (GRIOC). Cultivation technology had a very significant effect on both measures across all years ($P < 0.001$). Over three years, High-Intensive systems produced the highest average GYV (69,068 RUB/ha) and GRIOC (43,087 RUB/ha), followed by Intensive (GYV: 67,359; GRIOC: 43,407), while Basic technology had the lowest (GYV: 56,546; GRIOC: 35,243). This shows that increased inputs of fertilizers, crop protection, and management significantly improve economic returns.

Among varieties, Belyana achieved the highest mean GRIOC (42,097 RUB/ha) and GYV (65,721 RUB/ha), outperforming Agros (GRIOC: 40,330; GYV: 63,954) and Radmira (GRIOC: 39,311; GYV: 62,935). Varietal differences were statistically significant for both traits ($P \leq 0.007$), indicating genotype-specific economic responsiveness. The mean analysis shows that the mean values of GRIOC and GYV increase with improved cultivation technology use. Treatment plots amended with basic and high-intensive cultivation technologies exhibit the lowest and highest economic values, respectively. Findings indicate a differential genotypic response of spring wheat to improving cultivation technology for the economic parameters GRIOC and GYV. The profitability of the production system is an essential factor in technology evaluation, depicting the correlation between production value return and direct production costs. Analysis indicates that the production profitability of spring wheat cultivars was higher with improved cultivation technologies than with basic technology.

These findings align with studies showing high-yield, high-return systems under favorable conditions [311, 331, 321]. However, they contrast with low-input profitability reports [333], likely due to differences in genotypes, agroecology, and input regimes. The findings divulge that improved farming techniques (especially high-intensity farming methods) significantly boost both grain yield value (GYV) and gross return increase over control (GRIOC). This conclusion underlines the financial benefits of intensifying agricultural inputs (like fertilizers, pesticides, and management strategies) to maximize wheat profitability. The findings suggest that wheat farmers, including other cereal farmers, could use harmonized intensive technology for resource-poor farmers and high-intensive technology for commercial farming, which can provide considerable economic returns even with increased input expenses and encourage their wider implementation. Furthermore, the varying responses of wheat varieties (Belyana, Agros, and Radmira) to cultivation intensity highlight the financial significance of choosing the right genotype-technology pairings. The Belyana variety, which consistently records the highest economic metrics (GRIOC and

GYV), emerges as the most financially promising option, especially in high-input situations. Consequently, farmers could enhance economic efficiency by opting for varieties that respond well to specific management intensities. The study demonstrated that improving economic sustainability in wheat production can be achieved through advanced cultivation technologies and suitable variety selection. This emphasizes the significance of strategic decision-making in agriculture, highlighting the necessity for balanced approaches that consider ecological conditions, economic factors, and the adaptability of specific varieties to cultivation technologies.

Table 3.22 - Agroeconomic estimates of varieties and cultivation technologies on the increase in gross return over control and grain yield value of three spring wheat varieties

Parameters/ Treatments	GR_{IOC} - Rubles.ha^{-1}			GY_V - Rubles.ha^{-1}		
	2022	2023	2024	2022	2023	2024
Factor A: Cultivation Technology						
Basic	30,027	35,219	40,484	51,007	56,669	61,963
Intensive	44,393	41,301	44,526	67,993	62,502	71,582
High -intensive	45,380	37,999	45,882	70,093	66,951	69,068
P-value	0.001***	0.002**	<.001***	<.001***	<.001***	<.001***
LSD $_{5\%}$	4,617.6	1,899.6	1,181.8	4,617.6	1,899.6	1,181.8
Standard error (A)	2037.0	838.0	521.3	2037.0	838.0	521.3
CV%	5.1	2.2	1.2	3.2	1.4	0.8
Factor B: Varieties						
Agros	43,776	29,395	47,820	66,873	53,262	71,727
Belyana	44,709	37,966	43,615	67,807	61,833	67,522
Radmira	31,316	47,159	39,458	54,413	71,027	63,365
P-value	0.007*	<.001***	<.001***	0.007*	<.001***	<.001***
LSD $_{5\%}$	6,253.0	2,382.2	167.4	6,253.0	2,382.2	167.4
Standard error (B)	2758.4	1050.9	73.8	2758.4	1050.9	73.8
CV%	6.9	2.8	0.2	4.4	1.7	0.1

GRIOC=increase in gross return over control, GYV=grain yield value, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant

5.3.2. The interaction of variety and cultivation technologies impacted the increase in gross return over control (GR_{IOC}) and grain yield value (GY_V) of three spring wheat cultivars

Table 3.23 reveals the interactive effects of spring wheat varieties and cultivation technologies on Gross Return Increase Over Control (GRIOC) and Grain Yield Value (GYV) from 2022 to 2024. The pooled data showed no significant interaction ($P > 0.618$) in 2022; however, in 2023 and 2024, it exhibited significant interaction effects of variety × technology ($P < 0.001$), reflecting strong year- responses to management and genetics, which can likely be driven by climatic variability and disease pressure.

The most economically productive combination was Belyana under High-Intensive technology, achieving the highest GRIOC (48,685 RUB/ha in 2024) and GYV (74,385 RUB/ha), closely followed by Agros × High-Intensive (GRIOC: 49,990; GYV: 75,690 in 2024). In contrast, Radmira under Basic technology recorded the lowest returns of GRIOC of 20,460 RUB/ha in 2022—highlighting its limited responsiveness to low-input systems.

The average analysis data showed that different combinations of variety and technology significantly influence these traits, with Belyana x high-intensive technology exhibiting the highest cost values of GRIOC (46,294 rubles ha-1) and GYV (71,648 rubles ha-1), followed by Agros x high-intensive with a cost value of GRIOC (45,142 rubles ha-1) and GYV (70,497 rubles ha-1). Radmira variety shows, on average, the lowest cost of GRIOC and GYV.

Across all years, High-Intensive technology consistently enhanced both GRIOC and GYV for all varieties, confirming that advanced inputs (NPK fertilizers, crop protection, growth regulators) significantly boost economic output. Belyana emerged as the most reliable high-performer, especially under intensified management, aligning with findings that genotype x management interaction drives profitability of winter wheat by 10–20% [262, 334]. The 15–20% yield gains reported with efficient P and K use [335] are mirrored in our results, where nutrient-rich, high-input systems elevated returns.

These findings reveal that maximizing wheat profitability requires matching high-performing varieties like Belyana and Agros with advanced cultivation technologies. For policymakers and extension services, promoting such integrated approaches—tailored to local conditions is key to sustainable intensification. Future research should assess the long-term resilience of these systems under climate stress and fluctuating input prices to ensure enduring economic and environmental sustainability.

Table 3.23 - Interactive effect of varieties and cultivation technologies on the increase in gross return over control and the grain yield value of three spring wheat varieties

Parameters	GR_{IOC} - Rubles.ha^{-1}			GY_V - Rubles.ha^{-1}		
	2022	2023	2024	2022	2023	2024
Treatment interactions						
Agros× Basic	35,160	23,957	45,076	56,140	45,407	66,555
Agros× Intensive	45,280	29,677	48,393	68,880	54,180	72,935
Agros× H. Intensive	50,887	34,550	49,990	75,600	60,200	75,690
Belyana× Basic	34,460	36,417	38,696	55,440	57,867	60,175
Belyana× Intensive	50,040	36,910	43,463	73,640	61,413	68,005
Belyana× H. Intensive	49,627	40,570	48,685	74,340	66,220	74,385
Radmira× Basic	20,460	45,283	37,681	41,440	66,733	59,160
Radmira× Intensive	37,860	47,410	41,723	61,460	71,913	66,265
Radmira× H. Intensive	35,627	48,783	38,970	60,340	74,433	64,670
Mean	39,933	38,173	43,631	63,031	62,041	67,538
P-value-	0.618^{ns}	<.001***	<.001***	0.618^{ns}	<.001***	<.001***
LSD $_{5\%}$	7674.5	2580.7	1 221.7	7674.5	2580.7	1221.7
Standard error (AxB)	4757.7	601.9	684.4	4757.7	601.9	684.4
CV (%)	11.9	1.6	1.6	7.5	1.0	1.0

GRIOC=increase in gross return over control, GYV=grain yield value, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

5.3.3. Influence of varieties and cultivation technologies on the economic analysis of increase in marginal returns (MR), net returns (NR), and the value-cost ratio (VCR) of three spring wheat cultivars 2022-2024

The analysis of variance for MR, NR, and VCR of three spring wheat varieties and cultivation technologies illustrated that the varietal effect significantly impacted MR, NR, and VCR ($P<.001$) in 2023 and 2024. In contrast, in 2022, there was no significant effect. On the contrary, the variance analysis shows a substantial impact regarding cultivation technology in 2022 with MR and NR ($P<0.002$). However, in 2023, no significant effect for these traits was observed in Table 3.24. It is important to note that, on average, NR shows statistical significance ($P<.001$), whereas MR and VCR do not exhibit significance for technology (Table 3.24).

The ANOVA analysis reveals that the Belyana variety has the highest MR (0.922 rub. ha-1) in 2022, followed by Agros (0.878rub. ha^{-1}), while Radmira recorded the lowest (0.344 rub. ha^{-1}). In 2023, Radmira had the highest MR (0.983 rub. ha^{-1}), whereas Agros had the lowest (0.226 rub. ha^{-1}). In 2024, Agros recorded the highest MR (1.006 rub. ha^{-1}), while Radmira had the lowest (0.657 rub. ha^{-1}).

In 2023, Radmira had the highest NR (23,291 Rub. ha^{-1}), whereas Agros had the lowest (5,527 Rub. ha^{-1}). In 2024, Agros recorded the highest NR (23,913 Rub. ha^{-1}), while Radmira had the lowest (15,551 Rub.

In analyzing for the VCR, Belyana (1.923 rub. ha-1) exhibited the highest in 2022, while Radmira recorded the lowest (1.342 rub. ha-1). In 2023, Radmira had the highest VCR (1.967rub. ha-1), whereas Agros had the lowest (1.211). Furthermore, in 2024, Agros recorded the highest VCR (2.006 rub. ha-1), while Radmira had the lowest (1.657). However, the average analysis shows that Belyana recorded the highest MR (0.780 rub. ha^{-1}), NR (18,472 Rub. ha^{-1}), and VCR (1,781rub. ha^{-1}) while Radmira recorded the lowest.

Table 3.24 - Agroeconomic estimates of varieties and cultivation technologies on the increase in marginal returns, net returns, and the value-cost ratio of spring wheat

Parameters/ Treatments	MR - Rubles. ha^{-1}			NR -Rubles. ha^{-1}			VCR - Rubles. ha^{-1}		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Factor B: Cultivation Technology									
Basic	0.433	0.553	0.886	9,047	13,769	19,005	1,431	1,622	1,886
Intensive	0.878	0.610	0.814	20,793	13,496	19,984	1,881	1,600	1,814
High -intensive	0.833	0.641	0.786	20,667	15,651	20,182	1,837	1,533	1,786
P-value	0.002**	0.103^{ns}	0.017*	0.002**	0.064^{ns}	0.098^{ns}	0.006*	0.061^{ns}	0.017^{ns}
LSD $_{5\%}$	0.153	0.085	0.05	4 164.7	1 899.6	1181.8	0196.1	0.073	0.055
Standard error (A)	0.068	0.0375	0.0243	1837.2	838.0	521.3	0.087	0.032	0.024
CV%	9.5	6.2	2.9	10.9	5.9	2.6	5.0	2.0	0.2
Factor B: Varieties									
Agros	0.878	0.226	1.006	20,678	5,527	23,913	1,884	1,211	2,006
Belyana	0.922	0.596	0.823	21,611	14,098	19,708	1,923	1,578	1,823
Radmira	0.344	0.983	0.657	8,218	23,291	15,551	1,342	1,967	1,657
P-value	0.008*	<.001***	<.001***	0.005**	<.001***	<.001***	0.006*	<.001***	<.001***
LSD $_{5\%}$	0.277	0.103	0.009	5736.1	2 382.2	167.4	0.2626	0.110	0.009
Standard error (B)	0.122	0.0455	0.0040	2530.4	1050.9	73.8	0.116	0.048	0.004
CV%	17.1	7.6	0.5	15.0	2.9	0.4	6.7	3.1	0.3

MR=marginal return, NR=net returns, VCR=value-cost ratio, CV=coefficients of variation, LSD=Least significant differences, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

Cultivation technologies had observable influences on MR, NR, and VCR. The highest average MR (0.767 rubs. ha-1) and VCR (1,765 rubs. ha-1) were recorded with intensive technology, while the highest NR (18,833rubs. ha-1) was recorded when high-intensive technology was employed.

It is worth noting that from 2022 to 2024, MR and VCR under intensive and high-intensive conditions had similar statistical values. Conversely, the NR shows statistically significant values in 2023 and 2024 under the intensive and high-intensive technologies Table 3.24. Findings also showed that when basic technology was applied, the economic parameters of MR, NR, and VCR showed the lowest cost values.

The research demonstrated that the variety Belyana exhibited the highest MR (0.780 rubs. ha-1), NR (18 472 rubs. ha-1), and VCR (1.781rubs. ha-1), proving a more economically viable cultivar with all technologies, indicating its adaptability characteristics in terms of nutrient utilization. Belyana was shown to withstand some key abiotic and biotic factors under field conditions, attaining the highest grain yield and consistent returns. These economic traits are key factors in considering farm profitability. MR is essential because it aids producers in setting profit-maximizing output levels, NR is necessary for assessing profitability and operational viability, and VCR guides farmers' decision-making on optimal input use and efficiency. In contrast, the Radmira variety underperformed under the basic production system. Regarding technology effects, high-intensive and intensive technologies outperformed basic technology. Although advanced cultivation technologies can be expensive and incur high production costs, they can improve yields and enhance profitability, thereby ensuring food security despite the increased global demand for food. The variation observed across years (2022-204) underscores the influence of external factors such as climatic conditions, disease incidence, and market volatility in determining economic outcomes, as shown in Table 3.24. The low economic return associated with basic technology and the Radmira variety highlights the necessity of selecting appropriate wheat varieties and cultivation technologies to ensure a better economic return.

The results align with previous studies by [336, 262, 326], which found that highly intensive technologies significantly enhance economic output. Though requiring substantial investment and expertise, they can increase yield and profitability. This was consistent with the observable output of intensive and high-intensive technologies. Thomson et al. [337] indicates that the adaptability of specific wheat varieties like Belyana under varied cultivation systems aligns with this variety's superior performance. Intensive agricultural practices can optimize economic return for hybrid genotypes [4, 326], mirroring the observed trend where technology and variety combinations significantly impacted wheat yield and profitability. The study emphasizes the economic advantages of innovative technology and the selection of hybrid cultivars, such as Belyana, for farmers, policymakers, extension workers, and research institutes. It demonstrates the necessity for breeding programs and research on environmentally adapted cultivars Table 3.24.

5.3.4. Interaction effect of varieties and cultivation technologies on marginal returns, net returns, and the value-cost ratio of spring wheat

Selecting appropriate technology is crucial for any farm's financial performance. Economic analysis offers a structured approach to evaluating various agricultural practices, enabling farmers to make better choices that maximize revenues and reduce costs [338, 229]. Consequently, enhancing spring wheat production to attain optimal yield and net benefits is crucial within Russia's varied agro-ecological zones. As indicated in the impact table 3.24, a similar trend occurred in the interactive field effect when the variety and technology interface. Findings show that 2023 and 2024 were statistically significant for MR, NR, and VCR ($P<.001$), as shown in Table 3.25.

The interactive effect of variety and cultivation technology was clearly observed in all years, varieties, and cultivation technologies, as shown in Table 3.25. In 2022, Belyana x intensive technology recorded the highest MR cash value (1.133 rubs. ha^{-1}), while in 2023, Radmira x basic technology (1.110 rubs. ha-1) supersedes, and in 2024, Agros x basic technology (1.100 rubs. ha^{-1}). A similar trend occurs with NR, where in 2022, Belyana x intensive technology recorded the highest (26,440 rubs. ha-1). In 2023, Radmira x basic technology showed (23,833rubs. ha-1). Moving forward, in 2024, Agros x high-intensive technology (24,290 rubs. ha^{-1}). Our findings also observed a similar drift with the VCR trait, with Belyana x intensive technology recorded the highest (2,120 rubs. ha-1) in 2022, and in 2023, Radmira x basic technology showed (2,100 rubs. ha-1), whereas in 2024 Agros x basic technology (2,100 rubs. ha-1) as shown in Table 3.25.

On average, the ANOVA analysis exhibited that with all treatments, the Belyana variety interacted better with high-intensive technology, recording the highest MR (0.824 rubs. ha^{-1}), NR (20,940 rubs. ha^{-1}), and VCR (1.828 rubs. ha^{-1}) respectively, following Agros attaining the second-best variety with high-intensive technology, Table 3.25. It is important to note that the Radmira variety was exposed to similar field conditions. Still, it shows the lowest average for all three traits under high-intensity technology. However, it performed better under intensive technology, suggesting that Belyana could be best used for poor resource farmers. The interesting scenario with the Radmira variety was that all these traits (MR, NR, and VCR) were increased when cultivated with intensive technology.

The result demonstrates the variability in economic parameter estimates depending on the combination of wheat and cultivation technology. Intensive and high-intensive technology, also known as advanced technology in wheat production, consistently outperformed basic technology in terms of economic returns, highlighting the importance of adopting resource-efficient cultivation methods. The varietal effect indicated that the Belyana hybrid variety demonstrated superior economic performance across technology levels, highlighting its genotypic characteristics for diverse wheat farming systems. The interesting scenario with the Radmira variety under intensive and high-intensive technologies stresses the need for economic assessments before resource allocation in any wheat production system. These findings are consistent with research by [338, 262, 326] that emphasizes the dual importance of varietal selection and appropriate cultivation technology to achieve maximum economic productivity. The study demonstrated the significance of implementing advanced technology in the wheat production system, suggesting Belyana for increasing yield and economic profitability. Wheat farmers focus on using these harmonized technologies; intensive and high-intensive methods, with Belyana and Agros varieties, to meet global food demand by 2050, as shown in Table 3.25.

Table 3.25 - Interactive effect of variety and cultivation technologies on marginal returns, net returns, and the value-cost ratio of spring wheat.

Parameters	MR -Rubles. ha^{-1}			NR - Rubles. ha^{-1}			VCR - Rubles. ha^{-1}		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Treatment interactions									
Agros × Basic	0.667	0.117	1.100	14,180	2,507	23,597	1,677	1,100	2,100
Agros × Intensive	0.900	0.213	0.970	21,680	5,174	23,851	1,917	1,200	1,970
Agros × H. Intensive	1.067	0.347	0.947	26,174	8,900	24,290	2,057	1,333	1,947
Belyana × Basic	0.633	0.697	0.803	13,480	14,967	17,217	1,640	1,667	1,803
Belyana × Intensive	1.133	0.510	0.773	26,440	12,407	18,921	2,120	1,500	1,773
Belyana × H. Intensive	1.000	0.580	0.893	24,914	14,920	22,985	2,010	1,567	1,893
Radmira × Basic	0.000	1.110	0.753	-520	23,833	16,202	0.977	2,100	1,753
Radmira × Intensive	0.600	0.937	0.700	14,260	22,907	17,181	1,607	1,900	1,700
Radmira× H. Intensive	0.433	0.903	0.517	10,914	23,133	13,270	1,443	1,900	1,517
P-value-	0.530^{ns}	$<.001^{***}$	$<.001^{***}$	0.640^{ns}	$<.001^{***}$	$<.001^{***}$	0.537^{ns}	$<.001^{***}$	$<.001^{***}$
LSD 5%	0.322	0.113	0.056	0.7334.0	2,580.7	1,221.7	0.323.6	0.1150	0.0557
Standard error (AxB)	0.204	0.0272	0.0278	4891.6	601.9	684.4	0.2009	0.035	0.0278
CV (%)	28.5	4.5	3.4	29.1	4.2	3.5	11.7	2.2	1.5

MR=marginal return, NR=net returns, VCR=value-cost ratio, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant

5.4. Break-even and Investment Recovery Analysis

5.4.1. The impact of varieties and cultivation technologies on the breakeven point (BEP) and payback period (PBP) of three spring wheat varieties 2022–2024

Table 3.26 presents the main effect of the breakeven point (BEP) and payback period (PBP) of three spring wheat and cultivation technologies. Generally, the break-even point refers to the level of production or sales at which total revenue equals total production costs, meaning there is neither a profit nor a loss. Regarding the economic cost of production, the breakeven point occurs when the production costs are fully covered by the revenue generated from selling produced goods. A low break-even point (BEP) is advantageous as it provides greater flexibility and profit potential. In contrast, a high break-even point necessitates increased sales efforts and may require pricing adjustments or cost control measures to maintain competitiveness [339, 340, 341]. The payback period is the time it takes for a farm enterprise to recover its initial cost from the net cash flows (savings or profit) it generates. According to [341], the shorter the payback period in any production system, the more attractive it becomes.

The analysis of variance on the main effect of BEP and PEP unraveled significant differences (P<.001) from 2022 to 2024 cropping years. The impact of variety in 2022 shows that the Belyana variety had the lowest BEP(0.333 t) recovery time and the shortest back period PEP (0.522); in 2023, Radmira showed the lowest BEP (0.337 t)recovery time, and the shortest back period PEP(0.506) In the year 2024, Agros variety exhibited the lowest BEP (0.333 t) recovery time and also the shortest back period PEP (0.500), suggesting an advantageous profit margin in each year depending on varieties. These variances could be related to external factors such as climate changes during the growing seasons, prevailing disease incidence, and the elite genotypic characteristics of each cultivar used in the study. However, it is essential to note which variety over the three years of production surpasses and exhibits superior traits over the others. The average varietal comparison shows that the

Belyana variety had the lowest BEP (0.358 t) and PBP (0.567), indicating that Belyana is profitable and has a short payback period, making it attractive for wheat production.

In analyzing the average impact of cultivation technology, it was evident that high-intensive cultivation technology, although associated with high production costs, proved to be the most attractive production system. It achieved the lowest BEP (0.360 t) and PBP (0.586), followed by intensive cultivation technology compared to Basic cultivation systems. These results highlight that high-intensive cultivation technology and the Belyana variety contributed to the fastest economic profitability in the study period. The results highlight the significance of varietal selection combined with the appropriate cultivation technologies to increase economic outputs. Belyana demonstrates superior performance in BEP and PBP, indicating its ability to have quicker returns relative to Agros and Radmira. Intensive and high-intensive technologies have shown significant improvements in economic parameters compared to basic technology, possibly due to their superior efficiency in resource use. The observed trends indicate that applying advanced cultivation methods and optimized input-use strategies improves economic viability.

Our research concurs with the findings from [339, 340, 262; 326], who opined that the role of elite varieties with disease resistance is a key factor in increasing wheat productivity and economic returns. Findings agree with the view that combining improved wheat varieties with advanced agronomic practices enhances probability and reduces financial risks for farmers [341, 339]. The analogy between this study and previous works of literature strengthens its findings and highlights the universal principles of economic optimization in wheat cultivation, as shown in Table 3.26. Selecting an appropriate wheat variety, such as Belyana, along with implementing advanced cultivation technologies like Intensive or High-intensive methods, is crucial for enhancing economic sustainability at the farm level. These practices mitigate financial risks and facilitate faster recovery of investments. This study provides policymakers with insights into developing subsidy schemes and extension programs that promote high-efficiency technologies and optimal variety selection.

Agricultural extension services can utilize this data to inform farmers about strategic resource management decisions, enhancing profitability in fluctuating climate and market conditions. The findings provide significant evidence for promoting sustainable and economically viable cereal production.

Table 3.26 - Agroeconomic estimates of varieties and cultivation technologies on the breakeven point and payback period of three spring wheat varieties 2022–2024

Parameters/ Treatments	BEP(t)			PBP		
	2022	2023	2024	2022	2023	2024
Factor A: Cultivation Technology						
Basic	0.433	0.390	0.348	0.733	0.654	0.556
Intensive	0.344	0.398	0.356	0.544	0.669	0.567
High -intensive	0.333	0.387	0.361	0.556	0.634	0.556
P-value	<.001***	0.204ns	0.030*	0.002**	0.186ns	0.444ns
LSD 5%	0.025	0.014	0.008	0.062	0.042	0.025
Standard error (A)	0.011	0.006	0.003	0.027	0.018	0.011
CV%	3.3	1.6	1.1	4,5	2.8	2.0
Factor B: Varieties						
Agros	0.344	0.451	0.333	0.533	0.823	0.500
Belyana	0.333	0.387	0.354	0.522	0.628	0.556
Radmira	0.433	0.337	0.377	0.778	0.506	0.622
P-value	<.001***	<.001***	<.001***	0.007**	<.001***	<.001***
LSD 5%	0.025	0.022	0.005	0.123	0.072	0.025
Standard error (B)	0.011	0.009	0.002	0.054	0.032	0.011
CV%	3.0	2.4	0.6	8.9	4.9	2.0

BEP = breakeven point, PBP = payback period, T= time, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

5.4.2. Interactive effects of variety and cultivation technologies on breakeven point (BEP) and payback period (PBP) of three spring wheat 2022–2024

Table 3.27 reveals significant variety × cultivation technology interactions for Breakeven Point (BEP) and Payback Period (PBP) in 2023 and 2024 (P < 0.001), though not significant in 2022. The most economically efficient combination was Belyana × High-

Intensive technology, which achieved the lowest mean BEP (0.30 t) and one of the shortest PBP (0.50) in 2022, closely followed by Agros under the same system (BEP: 0.30 t; PBP: 0.47). In contrast, Radmira × High-Intensive showed the highest BEP (0.40 t) and longest PBP (0.67 years), indicating lower economic resilience despite high inputs. In 2023, Radmira × basic interacted and recorded the shortest BEP (0.32 t) and PB (0.47 t), while in 2024, Agros × basic technology showed the least BEP (0.32 t) and PBP (0.05 t), respectively.

The average analysis of BEP across all treatment combinations shows values ranging from 0.344 to 0.399 recovery time. The lowest BEP indicates a better profit cost recovery time. The results show that Belyana x high-intensive technology had the lowest BEP (0.344 t) and PEP (0.55), indicating minimal time for production cost recovery and a shorter payback period compared to other treatment combinations. The year variation across treatment combinations for BEP and PBP, such as basic × Agros, suggests year-to-year variability, hence demonstrating environmental conditions, disease incidence, and differential genotypic response of spring wheat varieties.

The lower BEP values observed with high-intensive technology and Belyana demonstrate higher profitability potential, as farmers need more profit in a shorter time to cover their production costs and achieve profitability. The shorter PBP exhibited by high-intensive technology and Belyana also indicates improved economic efficiency and more attractive returns on this production system. These combinations are essential in ensuring increased yield, financial stability, and an eco-environmentally friendly system for wheat producers. According to [326, 4, 325, 331], selecting appropriate hybrid wheat varieties and combining optimized production systems can substantially increase wheat yield and economic parameters. This aligns with the observed improvement in BEP and PBP with the Belyana variety and the formulated production technology adopted in this study. Elite varieties and disease-resistant varieties like Belyana improved yields, reduced BEP, expedited PBP, and mitigated the risks associated with pests and diseases [262, 334, 339]. The variation across treatment combinations mirrors this conclusion, reinforcing the importance of genetic and harmonized technology for wheat productivity. Variety effects on grain yield and agronomic parameters indicate that high-intensive cultivation technologies are recommended for increasing spring wheat productivity to maximize net benefits. Therefore, they are essential for diverse agroecological zones of Russia and the globe. Thus, our study's findings lead to the conclusion that developing appropriate cultivation technologies is recommended for diverse environments in the country and the world. Implementing optimal technology and crop variety combinations can enhance profitability and reduce risks for farmers.

The findings emphasize the necessity for targeted agricultural support programs, including financial incentives for adopting efficient technologies and access to high-performance wheat varieties. These interventions can enhance the adoption of economically sustainable practices, thereby increasing overall agricultural productivity for discussion markers. For researchers and extension services, the observed economic variations require additional research into the long-term sustainability of these technological and varietal combinations across various environmental conditions. Ongoing research should refine recommendations to strengthen the financial viability of wheat farming systems.

Table 3.27. Interactive effects of varieties and cultivation technologies on breakeven point and payback period of three spring wheat varieties 2022–2024

Parameters	**BEP(t)**			**PBP**		
	2022	**2023**	**2024**	**2022**	**2023**	**2024**
Treatment interactions						
Agros× Basic	0.40	0.47	0.32	0.60	0.90	0.50
Agros× Intensive	0.33	0.45	0.34	0.53	0.83	0.50
Agros× H. Intensive	0.30	0.43	0.34	0.47	0.74	0.50
Belyana× Basic	0.40	0.37	0.36	0.60	0.59	0.57
Belyana× Intensive	0.30	0.40	0.36	0.47	0.66	0.60
Belyana× H. Intensive	0.30	0.39	0.35	0.50	0.63	0.50
Radmira× Basic	0.50	0.32	0.36	1.00	0.47	0.60
Radmira× Intensive	0.40	0.34	0.37	0.63	0.52	0.60

Radmira× H. Intensive	0.40	0.35	0.40	0.70	0.53	0.67
Mean	0.37	0.39	0.35	0.61	0.65	0.56
P-value-	0.461^{ns}	<.001***	0.003*	0.042*	<.001***	0.013*
LSD $_{5\%}$	0.034	0.022	0.010	0.132	0.074	0.041
Standard error (AxB)	0.019	0.006	0.007	0.070	0.024	0.030
CV (%)	5.2	1.6	1.8	11.6	3.7	5.4

BEP = breakeven point, PBP = payback period, T= time, CV=coefficients of variation, LSD=Least significant difference, while Student test was used to separate the means, ns= not significant, * =significant, **=very significant, ***=highly significant.

CONCLUSION

In our research conducted in 2022-2024, the following key results were obtained:

1. Intensive cultivation technologies significantly increased grain yield, with yields up to 4.91 t/ha under the high-intensive system (averaged across all varieties) compared to 3.99 t/ha under the basic system (averaged across all varieties). Over the three years, the Belyana variety demonstrated the highest yield, 4.64 t/ha (averaged across all technologies), outperforming Agros (4.51 t/ha) and Radmira (4.44 t/ha). Grain quality also improved with increasing cultivation intensity: maximum protein content reached 15.46% under the high-intensive system (averaged across varieties), and maximum gluten content was 25.24% under the same system (averaged across varieties). Among varieties, Radmira exhibited the highest gluten content, 25.15% (averaged across technologies), making it valuable for the baking industry.

2. Varieties Belyana and Agros demonstrated high performance of agronomic traits, depending on cultivation technology, including grain weight per spike and 1000-grain weight. Agros attained average grain weight per spike (1.59 g) and 1000-grain weight (40.45 g), while Belyana had (1.49 g) grain weight per spike, and (37.78 g)1000-grain weight compared to Radmira (1.50 g; 36.37 g). This confirms their genetic potential to produce large, high-yielding, and marketable grain, highlighting their potential for cultivation in systems prioritizing high grain quality.

3. Cultivation technologies substantially influence disease development: the intensive system shows the most significant reduction in severity of Septoria leaf blotch, powdery mildew, and Fusarium head blight. Belyana showed high resistance to Septoria leaf blotch, 30.23% incidence (under intensive technology). Radmira exhibited resistance to powdery mildew (1.72% severity) and Fusarium head blight (21.67% incidence), making it valuable for producing high-quality grain even under moderate input systems.

4. The highest economic efficiency was achieved by combining the high-intensive cultivation technology with the Belyana variety, which yielded the maximum values for grain yield value (GYV) of 65,721, net return (NR) of 18,472, marginal return (MR) of

0.780, and value-cost ratio (VCR) of 1,775. Although Radmira was less profitable under the basic system, it, however, showed significant economic improvement when intensive methods were applied, making it promising for low-input or subsistence farming.

5. The study confirmed that integrating disease-resistant varieties with optimal cultivation technologies enhances both productivity and economic efficiency of spring wheat. The findings can be used by farmers and breeders, as well as policymakers, to develop policies for sustainable wheat production.

❖ Practical Recommendations

- ❖ For farms in the Central Region of the Non-Black Earth Zone of the Russian Federation, the spring wheat varieties Belyana and Agros, grown with high-intensity technology, are recommended as top choices to increase yields and improve economic efficiency
- ❖ Although Radmira shows a lower yield, it exhibits enhanced resistance to key wheat diseases, including Fusarium head blight and powdery mildew, supporting its recommendation for cultivation in areas with high disease risk.
- ❖ In terms of gluten and protein content, Radmira consistently showed the highest values over all three years and can be recommended for producing high-quality bread-making and food-grade grain.

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APPENDIX

Appendix 1

ANOVA for plant height and spike length measured in spring Wheat

	Plant height (cm)				Spike length (cm)		
Source of variation	d. f.	s. s.	m. s.	v. r.	s. s.	m. s.	v. r.
Rep. stratum	2	16.604	8.302		0.9564	0.4782	
Rep.Variety stratum							
Variety	2	2246.009	1123.005	3713.53	8.055	4.0275	40.38
Residual	4	1.21	0.302	0.08	0.3989	0.0997	0.32
Rep.Technology stratum							
Technology	2	576.875	288.437	71.06	8.2828	4.1414	11.61
Residual	4	16.237	4.059	1.11	1.4266	0.3566	1.16
Rep.Variety.Technology stratum							
Variety.Technology	2	576.875	288.437	71.06	0.6313	0.1578	0.51
Residual	4	16.237	4.059	1.11	2.4568	0.3071	1.39
Rep.Variety.Technology.*Units*stratum							
Year	2	28503.467	14251.733	4748.86	46.1687	23.0844	104.19
Variety.Year	4	685.427	171.357	57.1	4.9653	1.2413	5.6
Technology.Year	4	379.213	94.803	31.59	5.1133	1.2783	5.77
VarietyTechnology.Year	8	354.416	44.302	14.76	8.6655	1.0832	4.89
Residual	36	108.039	3.001		7.9761	0.2216	
Total	80	33023.29			95.0967		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 2

ANOVA for number of spikelets^{-1}spike and number of seeds ^{1}spike

		Number spikelets^{-1}spike			Number seeds^{-1}spike		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep. stratum	2	1.232	0.616		4.527	2.264	2
Rep.Variety stratum							
Variety	2	1.4338	0.7169	2.58	126.831	63.415	40.65
Residual	4	1.1099	0.2775	0.22	6.24	1.56	0.15
Rep.Technology stratum							
Technology	2	16.698	8.349	9.51	194.104	97.052	16.14
Residual	4	3.5124	0.8781	0.7	24.054	6.013	0.56
Rep.Variety.Technology stratum							
Variety.Technology	4	1.1977	0.2994	0.24	32.806	8.201	0.77
Residual	8	10.0006	1.2501	2.91	85.346	10.668	2.03
Rep.Variety.Technology.*Units* stratum							
Year	2	150.3304	75.1652	175.02	355.002	177.501	33.73
Variety.Year	4	18.0538	4.5134	10.51	377.783	94.446	17.95
Technology.Year	4	16.3382	4.0846	9.51	145.128	36.282	6.89
VarietyTechnology.Year	8	10.6252	1.3282	3.09	176.706	22.088	4.2
Residual	36	15.4606	0.4295		189.462	5.263	
Total	80	245.9927			1717.988		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 3

ANOVA for weight of seed^{-1} spike and 1000 grain weight(g)

	Weight of seeds^{-1}spike (g)				**1000 grain weight(g)**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep. stratum	2	0.03133	0.01566		3.9978	1.9989	
Rep.Variety stratum							
Variety	2	0.35439	0.17719	3.62	231.4482	115.7241	91.17
Residual	4	0.19605	0.04901	2.16	5.0774	1.2694	21.65
Rep.Technology stratum							
Technology	2	0.74034	0.37017	26.45	239.1661	119.583	489.74
Residual	4	0.05598	0.014	0.62	0.9767	0.2442	4.17
Rep.Variety.Technology stratum							
Variety.Technology	4	0.26559	0.0664	2.93	30.9629	7.7407	132.04
Residual	8	0.18131	0.02266	0.9	0.469	0.0586	0.1
Rep.Variety.Technology.*Units* stratum							
Year	2	2.81085	1.40542	55.86	827.0424	413.5212	691.75
Variety.Year	4	0.43326	0.10832	4.3	58.8337	14.7084	24.6
Technology.Year	4	0.78598	0.19649	7.81	29.7022	7.4255	12.42
VarietyTechnology.Year	8	0.50491	0.06311	2.51	19.9974	2.4997	4.18
Residual	36	0.9058	0.02516	55.86	21.5205	0.5978	

Total	80	7.26579			1469.19		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 4

ANOVA for grain yield measured in spring wheat.

	Grain yield (t ha^{-1})			
Source of variation	d.f.	s.s.	m.s.	v.r.
Rep. stratum	2	0.08128	0.04064	
Rep.Variety stratum				
Variety	2	0.53453	0.26726	3.81
Residual	4	0.28038	0.07009	1.87
Rep.Technology stratum				
Technology	2	12.52916	6.26458	403.51
Residual	4	0.0621	0.01553	0.41
Rep.Variety.Technology stratum				
Variety.Technology	4	0.36003	0.09001	2.4
Residual	8	0.29991	0.03749	1.11
Rep.Variety.Technology.*Units*stratum				
Year	2	0.72371	0.36185	10.72
Variety.Year	4	13.34552	3.33638	98.81
Technology.Year	4	2.10338	0.52585	15.57
VarietyTechnology.Year	8	0.55965	0.06996	2.07
Residual	36	1.21553	0.03376	
Total	80	32.0952		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 5

ANOVA for gluten and protein content measured in spring wheat.

		Gluten (%)			Protein (%)		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep. stratum	2	0.02543	0.01272		0.03636	0.01818	
Rep.Variety stratum							

Variety	2	303.50691	151.75346	8843.19	18.33562	9.16781	146.4
Residual	4	0.06864	0.01716	0.36	0.25049	0.06262	2.04
Rep.Technology stratum							
Technology	2	567.05358	283.52679	11899.31	125.27451	62.63725	1222.56
Residual	4	0.09531	0.02383	0.49	0.20494	0.05123	1.67
Rep.Variety.Technology stratum							
Variety.Technology	4	59.45827	14.86457	307.94	22.27012	5.56753	181.48
Residual	8	0.38617	0.04827	1.29	0.24543	0.03068	0.65
Rep.Variety.Technology.*Units*stratum							
Year	2	160.47802	80.23901	2137.95	127.99895	63.99948	1359.73
Variety.Year	4	136.26716	34.06679	907.7	18.13568	4.53392	96.33
Technology.Year	4	181.18716	45.29679	1206.92	14.63679	3.6592	77.74
VarietyTechnology.Year	8	18.30321	2.2879	60.96	8.3158	1.03948	22.08
Residual	36	1.35111	0.03753		1.69444	0.04707	
Total	80	1428.188			337.399		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 6

ANOVA for Septoria incidence and severity measured in spring wheat

		Septoria incidence			**Septoria severity**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.

Rep. stratum	2	248.77	124.38		0.05574	0.02787	
Rep.Variety stratum							
Variety	2	1328.86	664.43	17	0.80667	0.40333	3.23
Residual	4	156.33	39.08	0.52	0.49981	0.12495	1.55
Rep.Technology stratum							
Technology	2	21030.25	10515.12	323.7	15.28074	7.64037	52.68
Residual	4	129.94	32.48	0.43	0.58019	0.14505	1.79
Rep.Variety.Technology stratum							
Variety.Technology	4	281.79	70.45	0.93	0.93037	0.23259	2.88
Residual	8	603.86	75.48	3.01	0.64648	0.08081	1.19
Rep.Var_a.CTech_b.*Units* stratum							
Samp_reg_DAS	3	5383.56	1794.52	71.51	4.42528	1.47509	21.65
Year	2	4118.67	2059.34	82.07	5.39685	2.69843	39.6
Var_a.Samp_reg_DAS	6	156.94	26.16	1.04	0.80148	0.13358	1.96
CTech_b.Samp_reg_DAS	6	294.44	49.07	1.96	1.17704	0.19617	2.88
Variety.Year	4	330.86	82.72	3.3	0.96148	0.24037	3.53
Technology.Year	4	566.98	141.74	5.65	2.59685	0.64921	9.53
Samp_reg_DAS.Yr	6	1224.54	204.09	8.13	8.88759	1.48127	21.74
Var_a.CTech_b.Samp_reg_DAS	12	71.3	5.94	0.24	0.91037	0.07586	1.11
Variety.Technology.Year	8	405.71	50.71	2.02	0.33037	0.0413	0.61
Var_a.Samp_reg_DAS.Yr	12	120.37	10.03	0.4	2.96148	0.24679	3.62
CTech_b.Samp_reg_DAS.Yr	12	245.37	20.45	0.81	1.75204	0.146	2.14

Residual	222	5570.83	25.09		15.12667	0.06814	
Total	323	42269.37			64.1275		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 7

ANOVA for powdery mildew incidence and severity measured in spring wheat

	Powdery mildew incidence				**Powdery mildew severity**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep. stratum	2	668.67	334.34		0.17019	0.08509	
Rep.Variety stratum							
Variety	2	62.19	31.1	1.91	0.98463	0.492	11.69
Residual	4	65.12	16.28	0.4	0.16852	0.04213	1.33
Rep.Technology stratum							
Technology	2	13075.15	6537.58	158.81	11.95056	5.975	165.05
Residual	4	164.66	41.17	1.02	0.14481	0.03620	1.14
Rep.Variety.Technology stratum							
Variety.Technology	4	219.75	54.94	1.36	0.38593	0.09648	3.04
Residual	8	323.77	40.47	2.64	0.25426	0.03178	0.37
Rep.Var_a.CTech_b.*Units* stratum							
Samp_reg_DAS	3	6831.1	2277.03	148.45	1.80877	0.60292	7.04
Year	2	266.82	133.41	8.7	12.16685	6.083	71.07
Var_a.Samp_reg_DAS	6	57.56	9.59	0.63	0.14179	0.02363	0.28

CTech_b.Samp_reg_DAS	6	22.38	3.73	0.24	1.01957	0.16993	1.99
Variety.Year	4	1162.81	290.7	18.95	1.17019	0.29255	3.42
Technology.Year	4	509.57	127.39	8.31	3.0437	0.76093	8.89
Samp_reg_DAS.Yr	6	1299.23	216.54	14.12	3.11586	0.51931	6.07
Var_a.CTech_b.Samp_reg_DAS	12	171.6	14.3	0.93	1.28321	0.10693	1.25
Variety.Technology.Year	8	799.69	99.96	6.52	0.4537	0.05671	0.66
Var_a.Samp_reg_DAS.Yr	12	204.48	17.04	1.11	1.58858	0.13238	1.55
CTech_b.Samp_reg_DAS.Yr	12	129.94	10.83	0.71	0.98469	0.08206	0.96
Residual	222	3405.25	15.34		19.00309	0.0856	
Total	323	29439.74			59.83889		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 8

ANOVA for Fusarium head blight incidence and severity measured in spring wheat

	Fusarium head blight incidence				**Fusarium head blight severity**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep. stratum	2	168.52	84.26		1.60679	0.80339	
Rep.Variety stratum							
Variety	2	150	75	1.78	0.81302	0.40651	1.76
Residual	4	168.52	42.13	2.92	0.92568	0.23142	1.04
Rep.Technology stratum							
Technology	2	7430.25	3715.12	300.93	28.08263	14.04132	96.3
Residual	4	49.38	12.35	0.86	0.58321	0.1458	0.65

Rep.Variety.Technology stratum							
Variety.Technology	4	140.12	35.03	2.43	0.51494	0.12873	0.58
Residual	8	115.43	14.43	0.84	1.78248	0.22281	2.38
Rep.Var_a.CTech_b.*Units* stratum							
Samp_reg_DAS	2	6835.19	3417.59	199.87	8.47468	4.23734	45.34
Year	2	898.77	449.38	26.28	17.00066	8.50033	90.95
Var_a.Samp_reg_DAS	4	20.37	5.09	0.3	0.6803	0.17008	1.82
CTech_b.Samp_reg_DAS	4	153.09	38.27	2.24	0.77664	0.19416	2.08
Variety.Year	4	616.05	154.01	9.01	0.60069	0.15017	1.61
Technology.Year	4	345.06	86.27	5.05	3.93537	0.98384	10.53
Samp_reg_DAS.Yr	4	140.12	35.03	2.05	7.61023	1.90256	20.36
Var_a.CTech_b.Samp_reg_DAS	8	43.21	5.4	0.32	0.57538	0.07192	0.77
Variety.Technology.Year	8	64.2	8.02	0.47	1.30035	0.16254	1.74
Var_a.Samp_reg_DAS.Yr	8	50.62	6.33	0.37	1.32011	0.16501	1.77
CTech_b.Samp_reg_DAS.Yr	8	175.31	21.91	1.28	2.92397	0.3655	3.91
Residual	160	2735.8	17.1		14.95364	0.09346	
Total	242	20300			94.46077		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 9

ANOVA for grain yield and agronomic efficiency potassium (AEK)

	Grain yield (t ha^{-1})				**Agronomic efficiency of nitrogen**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.

Rep of stratum	2	0.08128	0.04064		6.29	3.15	
Rep.Variety. stratum							
Variety	2	0.53453	0.26726	3.81	3.18	1.59	0.16
Residual	4	0.28038	0.07009	1.87	39.68	9.92	1.05
Rep. technology. stratum							
Technology	2	12.52916	6.26458	403.51	2211.77	1105.88	279.23
Residual	4	0.0621	0.01553	0.41	15.84	3.96	0.42
Rep. variety. Technology.stratum							
Variety. technology	4	0.36003	0.09001	2.4	55.21	13.8	1.46
Residual	8	0.29991	0.03749	1.11	75.86	9.48	0.92
Rep.variety.technology*units*stratum							
Year	2	0.72371	0.36185	10.72	804.78	402.39	39.15
Variety.year	4	13.34552	3.33638	98.81	139.47	34.87	3.39
Technology.year	4	2.10338	0.52585	15.57	495.07	123.77	12.04

Variety.technology.year	8	0.55965	0.06996	2.07	115.05	14.38	1.4
Residual	36	1.21553	0.03376		370.06	10.28	
Total	80	32.09518			4332.25		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 10

ANOVA for agronomic efficiency potassium (AEK) and phosphorus (AEP)

	Agronomic efficiency potassium				**Agronomic efficiency of phosphorus**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	1.547	0.774		6.29	3.15	
Rep.Variety. stratum							
Variety	2	1.596	0.798	0.3	3.18	1.59	0.16
Residual	4	10.522	2.63	1.08	39.68	9.92	1.05
Rep. technology. stratum							
Technology	2	651.926	325.963	324.31	2211.77	1105.88	279.23
Residual	4	4.02	1.005	0.41	15.84	3.96	0.42
Rep. variety. Technology.stratum							
Variety. technology	4	17.791	4.448	1.83	55.21	13.8	1.46
Residual	8	19.439	2.43	0.87	75.86	9.48	0.92

Rep.variety.technology*units*stratum							
Year	2	232.156	116.078	41.51	804.78	402.39	39.15
Variety.year	4	40.612	10.153	3.63	139.47	34.87	3.39
Technology.year	4	129.732	32.433	11.6	495.07	123.77	12.04
Variety.technology.year	8	31.9	3.988	1.43	115.05	14.38	1.4
Residual	36	100.667	2.796		370.06	10.28	
Total	80	1241.91			4332.25		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 11

ANOVA for partial factor productivity nitrogen (PFPN) and potassium (PFPK)

	Partial factor productivity nitrogen				**Partial factor productivity potassium**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	27.55	13.77		5.665	2.833	
Rep.Variety. stratum							
Variety	2	175.84	87.92	4.1	35.243	17.621	3.71
Residual	4	85.78	21.45	2.25	19.022	4.756	1.91
Rep. technology. stratum							

Technology	2	87296.5	43648.25	8289.91	1819.387	909.694	918.29
Residual	4	21.06	5.27	0.55	3.963	0.991	0.4
Rep. variety. Technology.stratum							
Variety. technology	4	71.3	17.82	1.87	16.621	4.155	1.67
Residual	8	76.26	9.53	0.89	19.867	2.483	1.08
Rep.variety.technology*units* stratum							
Year	2	570.6	285.3	26.56	69.145	34.573	15.07
Variety.year	4	6051.5	1512.88	140.84	1048.805	262.201	114.27
Technology.year	4	1705.93	426.48	39.7	220.329	55.082	24
Variety.technology.year	8	2136.68	267.08	24.86	134.267	16.783	7.31
Residual	36	386.71	10.74		82.607	2.295	
Total	80	98605.72			3474.922		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 12

ANOVA for partial factor productivity phosphorus (PFPP) and increase in gross return over control (GR_{IOC})

	Partial factor productivity phosphorus				increase in gross return over control (GR_{IOC})		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	21.319	10.66		1.61E+07	8.04E+06	
Rep.Variety. stratum							
Variety	2	135.006	67.503	3.48	1.07E+08	5.36E+07	3.9
Residual	4	77.632	19.408	2.02	5.50E+07	1.38E+07	1.87
Rep. technology. stratum							
Technology	2	27560.688	13780.344	3395.09	1.20E+09	6.00E+08	198.01
Residual	4	16.236	4.059	0.42	1.21E+07	3.03E+06	0.41
Rep. variety. Technology.stratum							
Variety. technology	4	54.954	13.739	1.43	7.26E+07	1.82E+07	2.47
Residual	8	76.828	9.603	1.05	5.87E+07	7.34E+06	1.11
Rep.variety.technology*units *stratum							
Year	2	333.349	166.674	18.26	4.19E+08	2.10E+08	31.6

Variety.year	4	4372.032	1093.008	119.77	2.64E+09	6.59E+08	99.33
Technology.year	4	1050.748	262.687	28.79	4.37E+08	1.09E+08	16.49
Variety.technology.year	8	919.603	114.95	12.6	1.13E+08	1.41E+07	2.12
Residual	36	328.519	9.126		2.39E+08	6.63E+06	
Total	80	34946.913			5.37E+09		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 13

ANOVA for grain yield value (GYv) and marginal returns (MR)

	Grain yield value				**Marginal returns**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	1.61E+07	8.04E+06		0.02659	0.01329	
Rep.Variety. stratum							
Variety	2	1.07E+08	5.36E+07	3.9	0.19662	0.09831	3.7
Residual	4	5.50E+07	1.38E+07	1.87	0.10621	0.02655	2.01
Rep. technology. stratum							
Technology	2	2.50E+09	1.25E+09	411.84	0.15412	0.07706	19.45

Residual	4	1.21E+07	3.03E+06	0.41	0.01585	0.00396	0.3
Rep. variety. Technology.stratum							
Variety. technology	4	7.26E+07	1.82E+07	2.47	0.1223	0.03058	2.31
Residual	8	5.87E+07	7.34E+06	1.11	0.10573	0.01322	1.16
Rep.variety.technology*units*stratum							
Year	2	4.64E+08	2.32E+08	34.96	0.69587	0.34793	30.63
Variety.year	4	2.64E+09	6.59E+08	99.33	4.79673	1.19918	105.56
Technology.year	4	4.01E+08	1.00E+08	15.11	1.00772	0.25193	22.18
Variety.technology.year	8	1.13E+08	1.41E+07	2.12	0.29992	0.03749	3.3
Residual	36	2.39E+08	6.63E+06		0.40896	0.01136	
Total	80	6.67E+09			7.93662		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 14

ANOVA for net returns (NR) and value-cost ratio (VCR)

	Net returns	**Value-cost ratio**

Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	1.85E+07	9.26E+06		0.03037	0.01519	
Rep.Variety. stratum							
Variety	2	1.07E+08	5.36E+07	4.36	0.19942	0.09971	4.06
Residual	4	4.93E+07	1.23E+07	1.58	0.09835	0.02459	1.91
Rep. technology. stratum							
Technology	2	3.76E+08	1.88E+08	70.85	0.158	0.079	15.12
Residual	4	1.06E+07	2.65E+06	0.34	0.02089	0.00522	0.41
Rep. variety. Technology.stratum							
Variety. technology	4	7.26E+07	1.82E+07	2.33	0.11251	0.02813	2.19
Residual	8	6.22E+07	7.78E+06	1.2	0.10273	0.01284	1.08
Rep.variety.technology*units*stratum							
Year	2	3.97E+08	1.99E+08	30.63	0.6991	0.34955	29.49
Variety.year	4	2.64E+09	6.59E+08	101.64	4.82839	1.2071	101.85

Technology.year	4	4.76E+08	1.19E+08	18.35	1.03503	0.25876	21.83
Variety.technology.year	8	1.13E+08	1.41E+07	2.17	0.30563	0.0382	3.22
Residual	36	2.33E+08	6.48E+06		0.42666	0.01185	
Total	80	4.55E+09			8.01709		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio

Appendix 15

ANOVA for breakeven point (BEP) and payback period (PBP)

	Breakeven point				**Payback period**		
Source of variation	d.f.	s.s.	m.s.	v.r.	s.s.	m.s.	v.r.
Rep of stratum	2	0.0006222	0.0003111		0.003854	0.001927	
Rep.Variety. stratum							
Variety	2	0.0084963	0.0042481	8.34	0.060988	0.030494	4.64
Residual	4	0.002037	0.0005093	3.31	0.026272	0.006568	3.31
Rep. technology. stratum							
Technology	2	0.0137556	0.0068778	35.37	0.052032	0.026016	37.7
Residual	4	0.0007778	0.0001944	1.27	0.00276	0.00069	0.35

Rep. variety. Technology.stratum							
Variety. technology	4	0.0026815	0.0006704	4.36	0.031094	0.007773	3.91
Residual	8	0.0012296	0.0001537	1.19	0.015891	0.001986	1.12
Rep.variety.technology*units* stratum							
Year	2	0.0182889	0.0091444	70.54	0.140573	0.070286	39.52
Variety.year	4	0.1132815	0.0283204	218.47	0.827842	0.20696	116.37
Technology.year	4	0.0417111	0.0104278	80.44	0.160264	0.040066	22.53
Variety.technology.year	8	0.0052519	0.0006565	5.06	0.109232	0.013654	7.68
Residual	36	0.0046667	0.0001296		0.064022	0.001778	
Total	80	0.2128			1.494825		

d.f=degree of freedom, s.s= sum of squares, m.s=mean squares, v.r=variable ratio