

Brief information about the project

Name of the project	AP26195823 — Study of the Effects of Light-Converting Films on the Accumulation of Bioactive Compounds in Fruits
Relevance	In the context of climate change, population growth, and limited resources, the challenge of increasing both the yield and quality of agricultural products has become particularly urgent. Solar radiation is not always optimal for plant growth: a significant portion of ultraviolet and yellow–green light is either poorly utilized or even harmful to plants. Light-converting films make it possible to effectively transform less useful wavelengths into red and blue light, thereby stimulating photosynthesis and enhancing the accumulation of bioactive compounds (such as vitamins, antioxidants, and sugars) in fruits. This leads to improved nutritional value and consumer quality of agricultural produce. This topic is especially relevant for Kazakhstan and Central Asia, where protected cultivation is widely used under conditions of intense solar radiation. The development of domestically produced light-converting films contributes to import substitution, cost reduction, and the sustainable development of the agro-industrial sector. The global market for greenhouse films is rapidly expanding, and the segment of light-converting materials represents one of the most promising areas in modern agricultural technologies.
Purpose	The primary objective of the project is to investigate the effects of light-converting films on the accumulation of bioactive compounds in fruits, with the aim of enhancing their nutritional value and improving product quality. The project is focused on the development of technologies that will contribute to increasing crop yields and improving the consumer properties of agricultural products.
Objectives	🎬 Development of the composition and structure of light-converting films; 🎬 Investigation of the spectral characteristics of light-converting films; 🎬 Study of the effects of light-converting films on photosynthesis and plant growth; 🎬 Optimization of application conditions of the films for different crops; 🎬 Evaluation of the impact of light-converting films on fruit yield and quality;

	 Analysis of the economic feasibility and environmental safety of using light-converting films.
Expected and achieved results	According to the 2025 schedule, the expected results included conducting a literature review, selecting components for light-converting films, performing laboratory testing of materials, developing and producing laboratory samples of the films, and preparing and submitting an application for a utility model patent in the Republic of Kazakhstan. As of the completion of phases 1–5, all planned tasks have been fully accomplished. An analytical review of scientific and patent literature on light-converting films and their effects on plants was conducted. Components of the organo-inorganic composition (PET, PVA, perylene dye, SiO₂, and functional additives) were selected and optimized, and laboratory samples of two types of light-converting films—red and blue—were produced. Comprehensive laboratory testing of optical, physico-chemical, and performance characteristics was carried out. The resulting films have a thickness of $48 \pm 2 \mu\text{m}$, transparency of 87–91%, and exhibit high mechanical strength as well as thermal and light stability, remaining resistant to temperatures up to 80 °C, high humidity, and prolonged UV exposure while retaining up to 95% of their initial properties. The composition demonstrated high homogeneity and stability. Red films effectively convert ultraviolet and yellow–green light into the red region of the spectrum, stimulating photosynthesis, biomass growth, and fruit ripening, while blue films convert light into the blue region of the spectrum, promoting the accumulation of bioactive compounds such as phenolic substances, vitamins, and antioxidants, thereby enhancing the nutritional value and quality of the produce. A utility model patent has been obtained in the Republic of Kazakhstan. The results achieved fully meet the planned objectives for 2025 and provide a solid foundation for conducting field trials and evaluating the accumulation of bioactive compounds in fruits in 2026–2027 (phases 6–17).
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Usage	In the context of climate change, population growth, and limited resources, increasing both the yield and quality of agricultural products has become particularly urgent. Solar radiation is not always optimal for plant growth, as a significant portion of ultraviolet and yellow–green light is either poorly utilized or even harmful. Light-converting films provide an effective means of transforming less useful wavelengths into red and blue light, thereby stimulating photosynthesis and enhancing the accumulation of bioactive compounds, such as vitamins, antioxidants, and sugars, in fruits. This improves both the nutritional value and consumer quality of agricultural produce. The topic is especially relevant for Kazakhstan and Central Asia, where protected cultivation is widely used under conditions of intense solar radiation. The development of domestically produced light-converting films also contributes to import substitution, cost reduction, and sustainable development of the agro-industrial sector. The primary objective of this project is to investigate the effects of light-converting films on the accumulation of bioactive compounds in fruits, with the aim of enhancing nutritional value and improving product quality. The project focuses on the development of technologies that can increase crop yields and improve the consumer properties of agricultural products. Key tasks include the development of the composition and structure of light-converting films, investigation of their spectral characteristics, study of their effects on photosynthesis and plant growth, optimization of application conditions

for different crops, evaluation of their impact on fruit yield and quality, and analysis of economic feasibility and environmental safety.

According to the 2025 schedule, the expected outcomes included a literature review, selection of film components, laboratory testing of materials, development and production of laboratory film samples, and preparation and submission of a utility model patent application in the Republic of Kazakhstan. As of the completion of phases 1–5, all planned tasks have been fully accomplished. An analytical review of scientific and patent literature on light-converting films and their effects on plants was conducted. Components of the organo-inorganic composition (PET, PVA, perylene dye, SiO₂, and functional additives) were selected and optimized. Laboratory samples of two types of films—red and blue—were produced, and comprehensive laboratory testing of optical, physico-chemical, and performance characteristics was carried out. The resulting films have a thickness of $48 \pm 2 \mu\text{m}$, transparency of 87–91%, and high mechanical strength, thermal stability, and resistance to prolonged UV exposure, maintaining up to 95% of initial properties. The composition demonstrated high homogeneity and stability. Red films effectively convert ultraviolet and yellow–green light into the red spectrum, stimulating photosynthesis, biomass growth, and fruit ripening, while blue films convert light into the blue spectrum, promoting the accumulation of bioactive compounds such as phenolic substances, vitamins, and antioxidants, thereby enhancing nutritional value and product quality. A utility model patent has been obtained in the Republic of Kazakhstan. The achieved results fully meet the 2025 objectives and provide a solid foundation for field trials and evaluation of bioactive compound accumulation in fruits in 2026–2027 (phases 6–17).

The developed red and blue light-converting films are intended for agricultural use, primarily under protected cultivation conditions such as greenhouses, hoop houses, and tunnel covers. Their main applications include covering greenhouses and creating light-converting screens for the cultivation of vegetables, including tomatoes, cucumbers, sweet peppers, strawberries, and others; improving the spectral composition of light reaching plants by converting ultraviolet and low-efficiency radiation into red light (stimulating photosynthesis, growth, and yield) and blue light (enhancing the accumulation of bioactive compounds and nutritional value); and serving as functional covering materials to extend the growing season and improve product quality in regions with intense solar radiation, including Kazakhstan and Central Asia.

The advantages of these films include increased yield and fruit quality without additional energy or chemical inputs,

	ease of application as standalone coverings or additional layers on existing greenhouse materials, and environmental and economic benefits through import substitution and material durability. The material is ready for scaling up and further implementation following completion of field trials.
Priority compared to real-world alternatives	In the context of climate change, population growth, and limited resources, increasing both the yield and quality of agricultural products has become particularly urgent. Solar radiation is not always optimal for plant growth, as a significant portion of ultraviolet and yellow–green light is either poorly utilized or even harmful. Light-converting films provide an effective means of transforming less useful wavelengths into red and blue light, thereby stimulating photosynthesis and enhancing the accumulation of bioactive compounds, such as vitamins, antioxidants, and sugars, in fruits. This improves both the nutritional value and consumer quality of agricultural produce. The topic is especially relevant for Kazakhstan and Central Asia, where protected cultivation is widely used under conditions of intense solar radiation. The development of domestically produced light-converting films also contributes to import substitution, cost reduction, and sustainable development of the agro-industrial sector. The primary objective of this project is to investigate the effects of light-converting films on the accumulation of bioactive compounds in fruits, with the aim of enhancing nutritional value and improving product quality. The project focuses on the development of technologies that can increase crop yields and improve the consumer properties of agricultural products. Key tasks include the development of the composition and structure of light-converting films, investigation of their spectral characteristics, study of their effects on photosynthesis and plant growth, optimization of application conditions for different crops, evaluation of their impact on fruit yield and quality, and analysis of economic feasibility and environmental safety. According to the 2025 schedule, the expected outcomes included a literature review, selection of film components, laboratory testing of materials, development and production of laboratory film samples, and preparation and submission of a utility model patent application in the Republic of Kazakhstan. As of the completion of phases 1–5, all planned tasks have been fully accomplished. An analytical review of scientific and patent literature on light-converting films and their effects on plants was conducted. Components of the organo-inorganic composition (PET, PVA, perylene dye, SiO₂, and functional additives) were selected and optimized. Laboratory samples of two types of films—red and

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The advantages of these films include increased yield and fruit quality without additional energy or chemical inputs, ease of application as standalone coverings or additional layers on existing greenhouse materials, and environmental and economic benefits through import substitution and material durability.

Compared to existing domestic and foreign analogs, including rare-earth complexes, quantum dots, and other classes of organic dyes, the developed films possess several competitive advantages. They combine **high transparency and minimal light loss** (87–91% in the visible range) with **excellent stability and durability** under high temperature, humidity, and prolonged UV exposure. Their **optimal thickness and manufacturability** ($48 \pm 2 \mu\text{m}$, high homogeneity, and good mechanical strength) make them simpler and more cost-effective to produce than quantum dot or rare-earth phosphor-based films. The films also offer a **dual-target**

	effect, with red films stimulating photosynthesis, growth, and yield, and blue films promoting the accumulation of bioactive compounds, allowing precise spectral tuning for specific crops and developmental stages. Economically and regionally, the use of readily available components and domestic patenting support import substitution, while foreign analogs are often more expensive and less adapted to the continental climate of Central Asia with high UV exposure. In summary, the developed films combine high spectral conversion efficiency, preservation of light intensity, stability, and simplicity of production, giving them a clear advantage for greenhouse horticulture in Kazakhstan and the region. They are expected to achieve comparable or superior effects on crop yield and quality while offering favorable technical and economic performance. The material is ready for scaling up and further implementation following the completion of field trials.
List of publications with links to them	 Mutushev A., Nuraly A., Sanat A., Shaukharova M., Yesimsiitova Z. (2026). Effect of Light-Converting Films on the Accumulation of Bioactive Compounds and Fruit Quality. <i>Academic Journal of Physical and Chemical Sciences</i>, 1(357), 366–378. https://doi.org/10.32014/2026.2518-1483.426  Mukhanov D., Mutushev A., Nuraly A., Sanat A. Integrated Morphological, Biochemical, and Transcriptomic Responses of Greenhouse Crops to Spectral Modification Using Light-Converting Films. <i>Proceedings of the International Conference 2025</i>, November 21–22, 2025. https://academicresearchlibrary.com/abstract-detail/3800
Patents	 Mutushev A.Zh., Nuraly A.M., Seisenova A.B., Sanat A.S., Suleimenova M.Sh., Shaukharova M.A., Zhumagul M.Zh., Kurmanbayeva M.S. Light-Converting Polymer Film. Utility Model Patent No. 11714, dated October 20, 2025.  Mutushev A.Zh., Nuraly A.M., Seisenova A.B., Sanat A.S., Suleimenova M.Sh., Shaukharova M.A., Zhumagul M.Zh., Aitzhan M.U. Method for Producing a Light-Converting Film. Application No. 2025/1288.1, dated December 24, 2025 (application filed, formal examination completed).