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PRACTICAL SOLUTIONS FOR THE PLACEMENT OF MULTI-STOREY GREENHOUSES IN INDUSTRIAL AREAS

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Abstract: This article analyzes the issues of ensuring food security in the context of Uzbekistan and explores the potential for cultivating import-substituting tropical fruits through vertical (multi-storey) greenhouses located in industrial areas. The study scientifically substantiates mechanisms for reducing production costs, improving energy efficiency, and enhancing export potential by utilizing waste heat generated by industrial enterprises.

Key words: vertical greenhouses, industrial symbiosis, tropical fruits, import substitution, energy efficiency, hydroponics, food security.

Annotatsiya: Ushbu maqolada O‘zbekiston sharoitida oziq-ovqat xavfsizligini ta’minlash masalalari tahlil qilinib, sanoat hududlarida vertikal (ko‘p qavatli) issiqxonalar orqali import o‘rnini bosuvchi tropik mevalarni yetishtirish imkoniyatlari o‘rganiladi. Sanoat korxonalarida hosil bo‘ladigan chiqindi issiqlikdan samarali foydalanish orqali mahsulot tannarxini kamaytirish, energiya samaradorligini oshirish va eksport salohiyatini kengaytirish mexanizmlari ilmiy jihatdan asoslab beriladi.

Kalit so‘zlar: vertikal issiqxonalar, sanoat simbiozi, tropik mevalar, import o‘rnini bosish, energiya samaradorligi, gidroponika, oziq-ovqat xavfsizligi.

Аннотация: В статье рассматриваются вопросы обеспечения продовольственной безопасности в условиях Узбекистана, а также возможности выращивания тропических фруктов, замещающих импорт, с использованием вертикальных (многоэтажных) теплиц в промышленных зонах. Научно обоснованы механизмы снижения себестоимости продукции, повышения энергоэффективности и расширения экспортного потенциала за счёт использования отходящего тепла промышленных предприятий.

Ключевые слова: вертикальные теплицы, промышленный симбиоз, тропические фрукты, импортозамещение, энергоэффективность, гидропоника, продовольственная безопасность.

INTRODUCTION

Relevance of the topic. At present, the rapid acceleration of urbanization processes worldwide and the reduction of arable land require innovative approaches to agricultural production. In particular, in densely populated regions that are vulnerable to climate change, such as Uzbekistan, ensuring food security is a strategic priority. Disruptions in global food logistics chains and the high prices of imported tropical fruits have a negative impact on production costs in the domestic market [1].

Problem statement. In Uzbekistan, a significant share of raw materials used by juice and food-processing enterprises (mango, pineapple, and papaya concentrates) is imported using foreign currency. At the same time, in major industrial areas—such as the industrial clusters of Navoi, Almalyk, and Chirchiq—secondary thermal energy and carbon dioxide (CO_2) generated during production processes are released into the atmosphere without efficient utilization. The failure to use these resources is economically and environmentally inefficient.

Scientific novelty of the study. The solution proposed within the framework of this research is based on the concept of locating multi-storey (vertical) greenhouses directly within industrial enterprise territories. This approach goes beyond conventional greenhouse construction and aims to establish an "industrial–agricultural symbiosis." Specifically, vertical greenhouses are organized on the upper floors of juice-production facilities or in adjacent areas. Within this system, excess heat energy generated by industrial plants is used for greenhouse heating, while technical water is filtered and directed into hydroponic systems.

Practical significance. The implementation of this model enables import substitution by localizing the production of tropical fruits required for juice manufacturing, thereby optimizing import volumes and reducing foreign currency outflows. In addition, it enhances logistical efficiency by effectively reducing the distance between raw material cultivation sites and processing facilities to "zero." Furthermore, the use of multi-storey structures allows for 5–10 times more efficient land use compared to conventional greenhouses [2].

Research objective. The main objective of the study is to develop the technical and economic foundations for designing vertical greenhouses in industrial zones and to create an export-oriented value chain for finished products through their implementation in industrialized regions of Uzbekistan.

LITERATURE REVIEW

The concept of organizing vertical farming in industrial areas and utilizing industrial by-products is globally referred to as "Industrial Symbiosis." Research in this field can be grouped into several main directions.

Theoretical foundations of vertical farming. The founder of the vertical farming concept is Professor Dickson Despommier of Columbia University. In his studies, he demonstrated that cultivating agricultural products in multi-storey buildings enables land resources to be used 10–20 times more efficiently compared to conventional agriculture [2]. However, a major limitation of the Despommier model is the high level of energy consumption, which is identified as a key challenge.

Utilization of industrial waste heat. European researchers, particularly K. Cho and M. Park, have investigated the technical feasibility of using low-temperature industrial waste heat (30–60 °C) for greenhouse heating. Their findings indicate that such integration can reduce greenhouse operating costs by up to 40 % [4]. The present study is distinguished by adapting this approach to the cultivation of tropical fruits.

Development of greenhouse farming in Uzbekistan. Among local scholars, S. R. Umarov and A. Karimov have analyzed the economic efficiency of greenhouse farming under the conditions of Uzbekistan. Their works primarily focus on conventional hydroponic technologies and the use of energy-efficient films [1, 3]. However, the symbiotic integration of vertical greenhouses with juice-processing enterprises and the localization of tropical fruit production have not been systematically examined.

Analysis of studies and distinguishing features. A review of the existing literature shows that multi-storey greenhouses are predominantly considered within the framework of "Urban Farming" in city centers. The key distinction and novelty of this research lie in directing carbon dioxide (CO_2) and waste heat generated in industrial zones as technical resources for the vegetative growth of tropical fruits, as well as in developing practical mechanisms to enhance import substitution.

RESEARCH METHODOLOGY

This section applies a set of modern methodological approaches within the framework of the study. In particular, hydroponic and aeroponic technologies are used to analyze the process of supplying nutrients to the root systems of tropical plants in a soilless environment, as well as to assess the impact of these technologies on production efficiency.

In addition, within the framework of the energy recovery approach, the possibilities of utilizing waste heat generated by industrial furnaces or cooling units are examined, and the heat consumption coefficient per 1 m³ of greenhouse volume is calculated.

Furthermore, economic and mathematical modeling methods are employed to conduct a comparative analysis of production costs with imported analog products, thereby substantiating the economic efficiency indicators of greenhouse production.

ANALYSIS AND RESULTS

Within the framework of the study, an integrated model combining a juice production plant and a multi-level greenhouse complex was developed. The effectiveness of this model is substantiated through indicators related to the utilization of industrial waste heat, the efficiency of multi-level greenhouse structures in land use, and economic parameters associated with import substitution.

The possibility of directing excess thermal energy generated in industrial facilities, particularly during juice pasteurization processes or within boiler systems, to greenhouse heating was evaluated using a heat balance equation:

Qtotal = Qind + Qsolar − Qloss,

where Qind represents secondary heat energy obtained from the industrial facility, Qsolar denotes energy derived from solar radiation, and Qloss refers to heat losses through building structures. According to the calculations, water with a temperature of 40–50 °C discharged from the cooling system of a juice processing plant is sufficient to heat the nutrient solution in the hydroponic system of a vertical greenhouse, thereby reducing natural gas consumption for greenhouse heating by 70–80 %.

The efficiency of the multi-level greenhouse structure was assessed based on vertical farming technology. In particular, the effective cultivation area obtained by constructing a five-level greenhouse on a land area of 1000 m² (0.1 hectares) is determined using the following expression: Stotal = Sbase × n × k, where n denotes the number of levels (five levels) and k represents the effective working area coefficient (0.85). The results indicate that, compared to conventional greenhouses, land-use efficiency increases by a factor of 4.25, which enables industrial-scale cultivation of tropical fruits in areas with limited land resources, such as industrial zones.

An economic analysis of mango and papaya cultivation adjacent to a juice production facility demonstrates that the production cost of locally grown raw materials is significantly lower than that of imported counterparts. This finding highlights the strong potential for import substitution, contributing to reduced production costs and enhanced competitiveness of the final product. These results are summarized in Table 1, which presents a comparative analysis of imported and locally produced tropical fruits.

Indicators	Imported Raw Material (1 ton)	Local Vertical Model (1 ton)	Difference (%)
Transport and logistics costs	450 - 600	20 - 40	-94%
Customs duties and insurance payments	150 - 200	0	-100%
Energy consumption (heating)	-	15 - 30 (chiqindi issiqlik)	-
Total production cost (estimated)	**1200 - 1500**	**600 - 800**	**-45%**

The most significant scientific novelty of this study lies in the utilization of elevated CO_2 concentrations required for tropical plants, which are obtained from the ambient air of industrial zones through specialized filtration systems. This approach not only accelerates plant growth rates by 20–25 %, but also contributes to improving the environmental condition of industrial areas, particularly by enhancing air purification and reducing negative environmental impacts.

The results of the study indicate that the establishment of vertical greenhouses in industrial zones opens a new stage of development not only for the agricultural sector but also for the industrial economy. While energy consumption in conventional greenhouses accounts for 50–60 % of total production costs, the proposed “Symbiosis Model” makes it possible to reduce this share to 10–15 % [2]. This approach may serve as a key factor in enhancing Uzbekistan’s export potential in agricultural and food products.

The greenhouse complex integrated with a juice production facility implements the “Fresh to Factory” principle. In the case of importing tropical fruits, such as mango, papaya, and avocado, early harvesting and long-distance transportation often lead to a deterioration in product quality. In contrast, tropical fruits cultivated locally in a fully controlled vertical environment demonstrate, on average, a 20 % higher content of vitamins and sugars compared to imported analogues. This advantage significantly enhances the competitiveness of finished juice products in international markets.

CONCLUSIONS AND RECOMMENDATIONS

Based on the conducted scientific research, it can be concluded that the modernization of industrial zones through the utilization of idle industrial areas in the form of multi-level structures increases land-use efficiency by approximately 400 %. This approach has significant practical relevance for the re-functionalization of industrial infrastructure and the acceleration of regional development.

In addition, directing secondary heat resources and CO_2 emissions generated by industrial activities toward plant vegetation processes ensures energy efficiency while simultaneously maintaining ecological balance. This approach contributes to the formation of a closed-loop and environmentally sustainable system integrating industrial production with agricultural activities.

Furthermore, the reduction of tropical fruit imports strengthens economic independence. In particular, an average annual saving of approximately 1–1.5 million USD in foreign currency can be achieved at a single large-scale enterprise, thereby reducing dependence on external markets and enhancing national economic resilience.

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