



A holistic approach to enhancing economic productivity via sustainable vegetable farming

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Article Info	Abstract
Article type: Research Article	The agricultural sector in Khuzestan Province faces significant challenges due to substantial waste in producing major vegetables and summer crops, driven by demands from neighboring regions. This study examines key factors contributing to post-harvest waste across the supply chain, from farm to table. Data collected via questionnaires from 30 stakeholders were analyzed using statistical methods, revealing that packaging, transportation, and storage duration critically influence waste levels. We then evaluated human resource productivity using an index-based approach, focusing on partial productivity measures. Additionally, simple linear programming and fuzzy linear programming techniques optimized energy use, revealing that labor costs dominate expenses, followed by machinery, with human and capital inputs constituting 70% of total costs. Findings suggest that smaller production units can enhance energy efficiency through expanded operational areas, while larger units can improve performance via better resource management. These insights can inform policies aimed at waste reduction, improved logistics, and energy-efficient technologies, thereby boosting productivity and ensuring the sustainability of Khuzestan's agriculture.
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Introduction

The issue of agricultural waste has emerged as a critical challenge in discussions surrounding economic policies on a global scale. This challenge poses a significant threat to food security, social, and economic well-being. According to recent analyses (Saadi et al., 2025a), the sheer amount of resources wasted due to agricultural inefficiencies exacerbates economic losses for countries worldwide. Management practices across the agricultural spectrum—encompassing planting, harvesting, and post-harvest operations—play a pivotal role. Poor management in these areas contributes to both quantitative and qualitative waste, impacting food supplies and farmers' livelihoods. Experts in the food industry estimate that around 25% of the income derived from oil is lost each year as a result of agricultural waste. This neglect of conversion and complementary industries results in food losses equivalent to the potential sustenance of 15 to 20 million people annually (Taherzadeh-Shalmai et al., 2023). Notably, in Iran, 80% of agricultural waste is concentrated in just 20 to 30 products, predominantly horticultural in nature. The perishable nature of these products makes them particularly susceptible to loss during various stages of production. Addressing the waste in this sector can significantly enhance food security for communities (Mostashari-Rad et al., 2021).

North Khuzestan is distinguished as a major hub for vegetable and summer crop production in Iran. This region presents unique marketing challenges, often leading to a mismatch between supply and market demand. As a result, farmers frequently incur losses, sometimes to the extent that harvesting becomes economically unviable, leading to crops being left in the fields. In such cases, the remnants are typically repurposed as livestock feed (Eyni-Nargeseh et al., 2023). Khuzestan province produced a remarkable 13.7 million tons of agricultural products in recent years, accounting for 11% of the nation's total output, and it ranks first in the country's agricultural production. Particularly within horticulture, Khuzestan contributed 12.7 million tons, representing

12% of national output despite encompassing only about 8% of Iran's land (FAO, 2023). Furthermore, agricultural exports from the province reached approximately 685,000 tons, constituting 22.6% of its non-oil exports, with vegetables and summer crops leading the figures. The northern region of Khuzestan has notably excelled in vegetable production, yielding over 500,000 tons, thereby playing a crucial role in the province's agricultural output. Given the high agricultural output in Khuzestan, it is crucial to focus on minimizing waste and increasing added value through transformation and complementary industries. This emphasis represents an urgent necessity, as efforts are underway to innovate and enhance the agricultural sector (Kaab et al., 2023).

Research into food waste across various contexts has underscored the substantial amounts generated at different stages of the food chain. In several studies, investigators have quantified waste production and explored potential mitigation strategies. The highlighted significant information gaps in waste management, revealing that when useful data is available, it is often fraught with uncertainties about effective solutions (Gustavsson et al., 2011). For instance, one study focused on food waste in India, home to over a billion people or 17% of the global populace. The findings suggested the need for diversification and mechanization within the agricultural sector (Rawat et al., 2018). The researchers proposed various strategies such as continuous monitoring, improved storage systems, enhanced marketing efforts, nutritional studies post-harvest, and more efficient food safety measures. These initiatives aim to bolster agricultural production, create jobs, and reduce waste. Another critical area of research has been the damage sustained by fruits during transportation—a significant concern impacting quality. Investigations into "roller bruising" revealed that repeated vibration forces during transport lead to physical injuries on the fruits, ultimately affecting their marketability (Hussein, 2015). Further studies evaluated sugarcane waste in Khuzestan, utilizing hierarchical analysis to

assess impactful factors throughout the sugarcane production process. Results indicated that harvesting stages contributed most significantly to waste, while land preparation had considerably less impact (Molaei Jafrodi et al., 2022). Moreover, researchers have addressed the potential recycling of fruit wastes into valuable products. Investigations into the nutritional characteristics of agricultural by-products, particularly those within Khuzestan, have resulted in recommendations to transform waste into useful commodities (Merino et al., 2022). Subsoiling is vital for crops like sugarcane, especially on compacted soils. Monitoring traditionally relies on manual gauges, limiting real-time adjustments. Developing a depth measurement system with real-time display and online data collection improves precision, enabling immediate corrections and detailed field mapping, ultimately enhancing subsoiling efficiency and accuracy in modern agriculture (Loveimi et al., 2025). The agricultural sector in northern Khuzestan is not only pivotal for local economic stability but also plays a crucial part in enhancing food security and providing employment. Nevertheless, the region grapples with numerous challenges that obstruct efficient vegetable production. These include outdated farming practices, ineffective resource management, and a lack of innovative strategies for waste reduction.

This study seeks to address these critical issues by proposing a comprehensive model aimed at enhancing economic productivity within the vegetable production sector, while simultaneously tackling waste management concerns. The model's significance lies in its dual focus on agricultural productivity and sustainable practices. Firstly, by improving production techniques, we aim to increase the yield per hectare, ensuring that local farmers can effectively compete in both domestic and international markets. Enhanced productivity not only uplifts farmers' income but also supports the overall economic framework of Khuzestan—where agriculture serves as a primary livelihood. Secondly, effective waste management in vegetable production emerges as an urgent

concern, often resulting in financial losses and detrimental environmental impacts. By integrating waste reduction strategies into our model, we aspire to minimize post-harvest losses, which can account for losses of up to 30% of total yields in certain circumstances. This integrated approach holds the promise of boosting profitability for farmers while fostering sustainable agricultural practices aligned with global efforts to reduce food waste and mitigate environmental harm. In summary, this study aims to bridge existing gaps in knowledge and practice by providing a robust framework for increasing vegetable production efficiency while fostering effective waste management strategies in northern Khuzestan Province. By elucidating these objectives and their significance, we hope to propel further research and policy initiatives that will enable the agricultural sector in the region to flourish sustainably. The intention behind exploring vegetable production in northern Khuzestan and developing a model for enhanced economic productivity is to closely analyze current practices, challenges, and opportunities surrounding vegetable cultivation. By comprehensively understanding the region's specific circumstances and evaluating factors affecting economic productivity, the goal is to propose a model that optimizes resources, enhances efficiency, and ultimately yields greater economic returns for local vegetable producers. By doing so, this study aspires to offer valuable insights and actionable recommendations that can bolster sustainable and profitable vegetable production in northern Khuzestan province. Integrating innovative techniques and resource management strategies can pave the way for long-term sustainability and prosperity in the agricultural sector of this vital Iranian region.

Materials and methods

Case study and data collection

This research employs a quantitative and applied approach, using statistical mathematics in a three-stage process: literature review, fieldwork, and data analysis, all aligned with the study's subject, hypothesis, and objectives. After collecting

data from respondents, we identified key definitions of waste and critical factors contributing to waste at various stages. The aim was to assess the current state of vegetable and greenhouse production in northern Khuzestan Province and to develop a model to enhance economic productivity. This involved a group of 30 participants divided into two literacy levels (above and below a bachelor's degree). We considered their roles in the production chain—producer, distributor, processing worker, or consumer and explored key concepts and significant factors leading to waste through a targeted questionnaire. The survey targeted individuals working in greenhouses for vegetable production in Dezful who utilize modern technologies, as well as those in the fruit and vegetable sector. This reflects the strategic importance of Khuzestan in meeting the needs of neighboring provinces. Participants included gardeners focusing on pre-harvest waste, representatives from agricultural jihad offices responsible for policy-making, food industry factory workers producing processed agricultural products, and agricultural research institutes addressing waste causes. Agricultural students also participated in the research.

Questionnaire results were validated with SPSS software. Content validity was assessed through qualitative methods and Lawshe's formula, while reliability was measured using Cronbach's alpha, yielding coefficients between 0.74 and 0.88. The questionnaires included multiple-choice responses on a Likert scale. The study incorporated data from 30 farms, utilizing a random survey of producers to gather information on various agricultural inputs, including seed quantities, fertilizer use, biocide application, energy sources, equipment, land area, and yield. The sample size was determined using Cochran's method (Cochran, 1977), and data collection was conducted through in-person interviews.

$$n = \frac{\frac{z^2 pq}{d^2}}{1 + \frac{1}{N} \left(\frac{z^2 pq}{d^2} - 1 \right)} \quad (1)$$

The sample size (n) needed is calculated using the number of farms in the target population (N), a reliability coefficient (z) of 1.96 for a 95% confidence level, an estimated population attribute proportion (p) of 0.5, the complement of the estimated proportion (q) also at 0.5, and an allowable error deviation from the average population (d) of 0.05.

Resource efficiency

In this study, we conducted a one-year cross-sectional analysis using two distinct questionnaires. The first questionnaire was designed to familiarize the team with the residential areas of the beneficiaries, while the second, a household questionnaire, collected information from the heads of households who were the decision-makers regarding production issues. The statistical sample consisted of 140 summer-working households in Dezful, selected through proportional and random stratified sampling methods. To evaluate and analyze manpower productivity, the study adopted an index approach that emphasized measuring partial productivity. The method for assessing manpower productivity in goods production involved calculating the ratio of added production value to the labor employed over a specific period, following the framework established by (Imran and Ozcatlbas, 2021). Additionally, the generalized Cobb-Douglas production function, as specified in (Nikkhah et al., 2021), was utilized.

$$Y = A L^{a_1} K^{a_2} \quad (2)$$

where Y is added value, L is labor, K is capital, a_1 , a_2 , and A are estimated by regression. If the natural logarithm is taken from both sides of equation (2), equation (3) is obtained (Cogin et al., 2016):

$$\ln Y = \ln A + a_1 \ln L + a_2 \ln K \quad (3)$$

We considered various crops cultivated in the study area. This model incorporates restrictions such as minimum and maximum thresholds that account for critical factors influencing crop production in the region. These factors include seasonal land availability, year-round water resources, machinery access hours, chemical fertilizer

usage, workforce availability, market demands, sales and export constraints, maximum cultivation area for each crop type, and considerations for crop rotation. The objective function is designed to optimize profits and minimize costs, thereby guiding the selection of optimal values for decision variables. Constraints related to resource access are collectively referred to as a set of constraints (Fnais et al., 2022). In the inferential analysis, multiple regression analyses were performed using a combined multiple method. The authors identified only one regression as optimal, with subsequent analyses based on its findings. The dependent variable in these regressions was total productivity related to the supervisor and family members, defined as the natural logarithm of the added value ratio of production products. This calculation considered only the working hours of the supervisor and family members, excluding those of daily wage workers from the denominator. The added value calculation deducted the cost of daily wage workers from gross income. Alternative regressions also evaluated total labor productivity, including that of the supervisor, family members, and daily wage workers. In this case, human labor productivity was determined using the natural logarithm of the added value ratio relative to the total working hours of all labor contributors. Data analysis for this study utilized SPSS, LINDO, and winSQB software.

Results and Discussion

Waste management

In examining the responses from different groups regarding the concept of waste, we found distinct perspectives among consumers (w1), producers (w2), distributors (w3), and employees in the processing sector (w4). Consumers favored the definition of waste as a change in quality, deeming it the most comprehensive, while they cited changes in quantity as less significant. Conversely, producers identified the third definition as the most complete and were least concerned with changes in quantity. Distributors also preferred the third definition and mentioned the fifth option—remains of garden products after

consumption—least frequently. Employees in the processing sector prioritized the change in quality but were least focused on changes concerning product safety. Addressing the challenges of sustainable food security within the context of a resistance economy in rural Khuzestan province requires a comprehensive examination. Controlling biases in self-reported data on perceptions of waste is crucial. Implementing mixed-methods research designs, which combine quantitative and qualitative approaches, can enhance understanding of how different stakeholders perceive waste. For instance, triangulating self-reported data with observational studies or expert assessments can validate participants' reports. The varying definitions of waste among consumers, producers, distributors, and processing employees highlight the complexities of food waste and sustainable food security. Consumers tend to view waste in terms of product quality, suggesting a focus on the user experience. Producers adopt a more technical perspective, while distributors prioritize logistical concerns. To further explore these diverse perceptions, conducting in-depth interviews or focus groups would be beneficial. Such dialogue can reveal underlying reasons for these differing definitions and how they can inform policy and practical interventions aimed at fostering a resistance economy focused on sustainability. Given the intricate relationship between food security and the resistance economy, a purely quantitative analysis is inadequate (Bortot Coelho et al., 2023). Thus, a qualitative research approach is essential. This study utilized qualitative methods, such as content analysis, semi-structured interviews, focus groups, and brainstorming sessions (Cherepovitsyn and Solovyova, 2022), to identify criteria for sustainable food security within a resistance economy framework. Through systematic coding of interviewee perspectives, we initially established 12 criteria and 65 sub-criteria. After collaborating with 35 experts in focus groups, we refined these to 7 criteria and 35 sub-criteria based on a consensus of 70% or more. These finalized criteria form a comprehensive framework for sustainable

food security in rural Khuzestan province, and it is recommended that agricultural planners integrate these insights into their strategic decision-making (Asadi et al., 2024). This study examines sugarcane waste in Iran, influenced by harvester type, variety, and field age. The H-8000 produces less waste than H-7000. Waste varies by variety and stage, with operational improvements offering opportunities for increased efficiency, sustainability, and profitability (Saadi et al., 2025b). This study compares energy use and environmental impacts of plant cane and ratoon sugarcane in Iran. Plant cane has higher energy inputs and outputs but is less efficient and more damaging environmentally. Ratoon cycles are more sustainable; recommendations include reducing machinery use and adopting conservation practices for better efficiency (Behnia et al., 2025).

Resource efficiency

The findings indicate that, regardless of land costs (whether rent or opportunity cost), wages are the primary contributor to production costs, followed by machinery expenses. The small size of farms and limited access to machinery increase the share of these costs. Overall, approximately 70% of costs are attributed to human and capital factors, while the share of consumption inputs is below 30%. Regression analysis (Table 1) reveals that specific indicators positively and significantly affect human labor productivity. These include the education level of seasonal workers (at least literacy and fifth grade), the logarithm of farm size relative to total working hours, cooperative membership of seasonal workers, frequent promotional visits (more than 20 times a year), and residence in villages with medium to high development levels. Conversely, the education level of skilled workers with diplomas or higher, their experience, and total assets show negative effects on productivity (Table 2). This study aimed to assess the impact of legal, philosophical, economic, environmental, educational, and personal factors on the professionalism of wheat farmers in Northern Khuzestan Province, Iran. Utilizing a causal-

comparative design, data were collected through surveys and questionnaires. The sample comprised 310 randomly-selected wheat farmers from a total of 23,485, with 302 questionnaires analyzed. The questionnaire was developed following an extensive literature review and was validated through multiple revisions by faculty members at Islamic Azad University of Garmsar, boasting a reliability of 0.81 based on Cronbach's alpha. Stepwise regression analysis found that economic variables significantly explained 77.2% of the variance in the dependent variable, while combined with environmental, legal, and educational factors, they accounted for 86.5% of the variability in optimal wheat production (Sabouri et al., 2018).

The goal is to highlight key aspects of production costs and labor productivity among wheat farmers in Northern Khuzestan Province, Iran. It was noted that labor and machinery costs constitute 70% of total production expenses, while consumption inputs make up less than 30%, underscoring the crucial role of labor in agricultural productivity. The regression analysis identifies several factors that influence human labor productivity. Notably, the education levels of summer workers, their farm experience, and membership in cooperatives positively correlate with productivity. On the other hand, the higher education levels of specific workers, such as Saifikar, and their accumulated assets can adversely affect productivity.

To translate these insights into actionable recommendations, focusing on several strategic areas would be beneficial. Firstly, implementing training and education programs for summer workers could significantly boost their efficiency and overall productivity, potentially through workshops on best agricultural practices or machinery operation. Secondly, addressing the challenges posed by small farm sizes and limited access to machinery could involve establishing community strategies like shared machine services or cooperative purchasing agreements to lower individual costs and enhance productivity.

Table 2. Results of regressions using equation 6 to analyze the factors affecting the productivity of manpower in vegetable production.

Independent variables	Estimated coefficient (€)	t value
The natural logarithm of the ratio of garden size to total working hours (square meters per hour)	0.354	7.125
Different size groups of farms (2 hectares and less in width from the origin):		
Larger than 2 to 4 hectares	-0.155	-1.844
Larger than 4 to 6 hectares	-0.17	2.160
Larger than 6 to 8 hectares	0.041	0.522
Larger than 8 to 10 hectares	0.184	2.567
Larger than 10 hectares	0.082	0.123
The natural logarithm of the number of farm plots	-0.042	0.596
Virtual variable for the supervisor's education level (illiterate across the origin):		
Reading and writing -1	0.146	2.259
Fifth elementary -1	0.107	1.771
The third guide	0.340	0.502
Diploma-1	-0.100	1.944
Higher than diploma-1	0.001	0.013
Natural logarithm of experience	0.139	2.852
Virtual variable for membership in a cooperative company	0.173	3.348
The ratio of the received loan amount to the current expenses per year	0.096	2.083
The natural logarithm of the total assets of Saifikar	-0.141	2.690
Visiting promoters to summer farms (11 to 20 times a year-1)	-0.062	-1.294
Promoters visiting summer farms (more than 20 times a year)	0.091	1.876
virtual variable for visiting promoters (at least 1 time per year-1)	-	-
The virtual variable of Asifikar's place of residence (in a village with a low level of development in width from the origin):		
Virtual variable for summer residence in a village with a high level of development-1	0.236	3.368
Virtual variable for summer worker residence in a village with medium development level -1	0.126	1.988
Coefficient of determination	0.646	-
Adjusted coefficient of determination	0.419	-
SEE	1.34	-
F ratio	12.85	-
Number of observations	180.00	-

*, ** and *** are statistically significant at the level of 10, 5 and 1 percent, respectively.

Moreover, enhancing cooperative membership by promoting the advantages of participation could lead to a more knowledgeable and productive workforce. Tailored support and incentives for workers with lower education levels may also increase their productivity, maximizing their potential. Regular engagement by agricultural promoters or extension officers through consistent visits can provide vital ongoing support and education to farmers.

These actionable strategies can help stakeholders effectively address the findings and improve productivity in wheat farming in the region. The insights on labor and

machinery costs present significant opportunities for policymakers and farmers to implement practical interventions aimed at boosting agricultural productivity and sustainability.

The data highlights that wages are a fundamental part of production costs, so strategies to enhance labor efficiency can notably affect overall agricultural expenses. Policymakers could concentrate on providing training programs that improve farm workers' skills, especially in smaller farms where labor intensity is high. Increasing workers' skill levels would enhance

productivity and lead to more efficient labor resource utilization.

Furthermore, since machinery costs are also substantial, and smaller farms frequently face challenges accessing modern equipment, policy interventions could include establishing cooperative purchasing programs or machinery rental systems. This approach allows farmers to share resources, distributing the costs of purchasing or renting machinery among a larger group. Supporting local cooperatives or associations that facilitate collective access to equipment would be advantageous.

Investing in educational initiatives for both workers and farmers could result in long-term benefits. Given the positive correlation between educational attainment and labor productivity, targeted programs aimed at improving education, especially among rural populations, can substantially enhance agricultural output. Policies encouraging higher education or vocational training in agricultural technologies could help bridge existing skill gaps.

Moreover, the research emphasizes the significance of the workers' environment, suggesting that development strategies should focus on community-level enhancements. Investments in infrastructure and community development in disadvantaged areas may improve laborers' living conditions, which could, in turn, enhance their productivity on farms.

Lastly, the importance of factors like cooperative membership and regular interactions with promoters highlights the value of social networks in agriculture. Encouraging farmer cooperatives and facilitating ongoing support from agricultural extension services could strengthen these networks, leading to better production practices and higher productivity.

In summary, interventions should concentrate on improving labor skill levels, enhancing access to machinery through cooperative strategies, investing in education, and promoting community development initiatives. By targeting these areas, policymakers can

cultivate a more efficient, productive, and sustainable agricultural sector.

Socio-political and economic challenges

The proposed model fails to adequately consider localized factors such as climate, market dynamics, and political conditions, all of which are vital for understanding the context of Khuzestan. Issues like government subsidies, water scarcity, and export restrictions significantly influence agricultural practices and productivity. To provide a clearer representation of the area's challenges, the model must incorporate these elements.

The analysis of waste revealed differing perceptions among stakeholders. Consumers view changes in quality as the most comprehensive concept of waste, considering changes in quantity to be less important. Producers, on the other hand, regard the third definition of waste as the most complete, placing less emphasis on changes in quantity. Distributors share a perspective similar to that of producers, while employees in the processing sector align more closely with consumers, highlighting the importance of quality changes. These varied viewpoints demonstrate the complexities of waste in the agricultural supply chain and emphasize the need for a nuanced understanding of food security within the resistance economy framework in Khuzestan.

Labor costs emerge as the primary contributor to production expenses, with machine costs closely following. The study reveals that approximately 70% of production costs are linked to human and capital factors, underscoring the significance of labor efficiency. Key findings indicate that education level and cooperative membership positively impact human labor productivity, while factors such as labor experience and total assets can negatively affect productivity. Understanding these dynamics is crucial for agricultural planners aiming to optimize labor resources in the small-scale farming context of Khuzestan.

An energy analysis of eggplant farming highlights a substantial requirement for

energy inputs, leading to significant outputs. The net energy benefits from eggplant cultivation offer valuable insights into sustainability, with the total energy input per hectare reaching 13.52 MJ, while production outputs are considerably higher, illustrating effective energy utilization. The study utilized linear programming and fuzzy linear programming to optimize energy benefits and minimize energy intensity, suggesting that larger farm sizes could enhance efficiency. Notably, fuzzy methods appeared to produce better outcomes in terms of energy intensity, adding complexity to the optimization of energy usage in agricultural practices throughout Khuzestan.

Given the intricate interplay of economic, environmental, and educational factors influencing agricultural productivity, it is essential to adopt a qualitative approach to explore the unique challenges in Khuzestan more thoroughly. This approach can enhance strategic decision-making for agricultural planners and contribute to the development of sustainable practices within the framework of the region's resistance economy. In summary, while the study highlights various aspects of sustainable food security and energy optimization, it underscores the importance of integrating localized contextual factors for a comprehensive understanding of agricultural dynamics in Khuzestan.

Conclusions

Vegetables and summer crops play a critical role in Khuzestan Province's agriculture, making up over 40% of farming activities. Dezful stands out in this regard, with the largest cultivation area (40%) and the highest production output (55%) in the region, particularly in its central section. More than 2,000 households rely on these crops for their livelihoods. This research aims to assess vegetable and summer crop cultivation in Dezful to enhance economic productivity.

The study identified key factors influencing productivity, such as educational levels of workers, farm size relative to working hours, cooperative membership, frequency of

promoter visits, and village development levels. While higher education and certain worker characteristics positively affected productivity, factors like experience and asset size had a negative impact. Linear programming techniques were used to recommend strategies for optimizing farm sizes. Suggestions included promoting growth for small and medium farms under stable management conditions, while advising larger farms to downsize for better production stability and energy efficiency. Future research should prioritize optimizing input and energy use while maintaining consistent planting areas.

This analysis highlights the need for regional decision-makers to effectively use resources to maximize productivity across diverse farm sizes. The study also explores intricate relationships among waste, productivity, energy consumption, and agricultural practices in rural Khuzestan. Different stakeholders—consumers, producers, distributors, and processing employees—view waste differently, underscoring the need for targeted educational initiatives and tailored strategies.

Furthermore, the reliance on human resources and machinery costs is evident, with regression analysis indicating that educational levels and cooperative involvement positively influence productivity. Collaborative purchasing of machinery could alleviate financial pressures and improve efficiency, necessitating prompt policy support. Lastly, the study recommends integrated approaches that encompass training, cooperative resource sharing, and optimized crop selection to enhance productivity and resilience in the face of food security and sustainability challenges in Khuzestan. By embracing these insights and implementing actionable strategies, stakeholders can significantly boost agricultural productivity and contribute to environmental sustainability.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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