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THE «THREE SISTERS» IN MODERN HUMAN NUTRITION AS AN INNOVATIVE INTEGRATION OF TRADITION, SCIENCE, AND BUSINESS

Annotation. *This paper explores the agroecological, cultural, nutritional, and business-related significance of the «Three Sisters» intercropping system - corn, beans, and squash-rooted in Native American agricultural traditions. By analyzing scientific studies and meta-analyses, the authors assess how this system enhances*

land-use efficiency, soil health, pest resistance, and dietary quality. The study highlights the potential of combining traditional knowledge with modern science and entrepreneurial strategies to advance sustainable food systems, support Indigenous food sovereignty, and create business opportunities in local and global agri-food markets. It also addresses challenges such as reconciling cultural and scientific paradigms and land accessibility.

Key words: *Three Sisters, intercropping, sustainable agriculture, agroecology, Native American agriculture, food security.*

Анотація. *У цій статті досліджується агроекологічне, культурне, харчове та бізнес-значення системи поєднання культур «Три сестри» – кукурудзи, квасолі та гарбуза, що бере свій початок у сільськогосподарських традиціях корінних американців. Аналізуючи наукові дослідження, автори оцінюють, як ця система підвищує ефективність землекористування, здоров'я ґрунту, стійкість до шкідників та якість харчування. Дослідження підкреслює потенціал поєднання традиційних знань із сучасною наукою та підприємницькими стратегіями для розвитку стійких продовольчих систем, підтримки продовольчого суверенітету корінних народів та створення бізнес-можливостей на місцевих та глобальних агропродовольчих ринках. Також розглядаються такі проблеми, як узгодження культурних та наукових парадигм і доступність землі.*

Ключові слова: *Три сестри, поєднання культур, стале сільське господарство, агроекологія, сільське господарство корінних американців, продовольча безпека.*

Introduction. The «Three Sisters» crops - corn (*Zea mays*), beans (*Phaseolus vulgaris*), and squash (*Cucurbita pepo*) - have long been staples of Native American agriculture [1]. Beyond their nutritional value, these crops hold cultural significance, symbolizing sustainable practices passed down through generations. Promoting them in modern nutrition programs also helps preserve Indigenous traditions, which were disrupted following European colonization. Historical accounts link colonial food

systems to the disruption of cultural foodways, including those of Native Americans and West Africans [2].

Despite these disruptions, Native and African American communities have shown resilience. This study explores how these communities have preserved and adapted food customs from 1619 to the COVID-19 pandemic. It also offers insights into sustainable alternatives for the U.S. food system.

Research Question:

How can traditional «Three Sisters» agronomic practices affect the nutritional properties of foods and improve food security in modern agroecosystems?

Objectives:

1. Examine the impact of traditional Three Sisters methods on modern nutrition and food security.

2. Analyze database research to consolidate current findings.

3. Compare Three Sisters intercropping (3SI) with single-crop farming in terms of nutrition, soil health, and sustainability.

Methodology. Academic databases including PubMed, Scopus, and Web of Science were searched using terms such as «Three Sisters», «intercropping», «nutritional impact», and «agroecology». Studies were selected based on relevance, access to full text, and recency (past 10 years preferred). Emphasis was placed on empirical studies, meta-analyses, and research involving both traditional practices and modern scientific assessments.

Research results. Global Intercropping Trends.

Cereal-legume intercropping is common in both developing and developed regions. Key factors such as sowing time, seed density, and nitrogen application influence the productivity of intercrops. A meta-analysis of 552 cases showed that earlier sowing and greater density increased a species' competitiveness [4]. Fertilizer use favored cereals over legumes, though early sowing of legumes softened this imbalance.

Another meta-analysis on corn-soybean intercropping found an average Land Equivalent Ratio (LER) of 1.32, showing higher land-use efficiency for intercrops

compared to monocultures. Relay intercropping systems sometimes reached LERs as high as 1.71 [5].

Cultural and Ecological Importance of 3SI. Revitalizing 3SI supports both cultural preservation and soil health. A study involving Native American growers showed that 3SI increased short-term soil respiration by 24 percent, reduced nitrate levels by 54 percent, and improved the carbon-to-nitrogen ratio by 32 percent [3].

The milpa system in Guatemala (a regional form of 3SI) highlights how crop diversity benefits subsistence farming. In 357 studied plots, combinations like corn-bean-potato yielded the highest Potential Nutrient Adequacy (PNA), surpassing monocultures. Milpa systems are more adaptable to local altitude, climate, and tradition-based needs [6].

LER values for 3SI range from 1.06 in the northeastern U.S. to 1.9 in Central Mexico. These ratios confirm that intercropping improves both yield and nutritional density. Corn-bean-potato systems showed the highest levels of essential nutrients like iron, zinc, vitamin C, and thiamine [6].

Pest Management and Sustainability. In addition to nutritional advantages, 3SI also improves pest control. Squash and beans increase maize's resistance to pests like the Asian corn borer. Maize grown in 3SI systems showed higher levels of defensive compounds and phytohormones, reducing pest survival and improving yield [7].

In China, intercropping corn with peas improved both land use efficiency (LER: 1.18–1.47) and water use efficiency (WER: 0.87–1.16). The use of mulch further increased yields and reduced water loss. An arrangement of 4 rows of corn with 4 rows of peas yielded the best results [8].

Nutritional benefits of the «Three Sisters» polyculture. Whether grown as a polyculture or a monoculture, maize provides enormous energy and protein. In «Three Sisters», protein from corn is also strengthened by beans and pumpkin proteins [9]. With the Three Sisters, farmers harvest about the same amount of energy as they would from a monoculture of corn, but they get a much higher protein yield from interplanting beans and pumpkins. Although beans yield less than corn, they

contain more than twice as much protein per unit. This means subsistence farmers will grow beans despite lower yields due to their high protein content. Surprisingly, a pumpkin monoculture provides more protein than a bean monoculture, mainly due to the contribution of pumpkin seeds.

Pumpkin seeds contain a significant amount of essential amino acids, while their pulp contains a minimal amount. A diet based on corn, beans, and squash can meet the basic human needs for energy and protein. However, I was also interested in evaluating how these foods could provide some of the vitamins and minerals needed for human health. Pumpkin flesh is one of the richest sources of vitamin A; people who regularly consume even moderate amounts of this vitamin will likely never become deficient in this vital vitamin. Beans and pumpkin seeds contain more calcium than corn or pumpkin flesh. Number of adults receiving annual energy and protein from monoculture mixtures compared to the Three Sisters. The first number in the monoculture mixture is the percentage of the area planted with corn; the second is the percentage of beans sown; and the third is the percentage of pumpkin plantings.

Even without nixtamalization, combining legumes (including pumpkin seeds) with corn in one's diet can provide high-quality protein and sufficient niacin to prevent pellagra. This underscores the importance of strategic food pairing to ensure a balanced and nutritious diet.

Corn provides enormous energy and modest protein levels, whether planted by itself or with other crops. Nixtamalization, the cooking of corn in an alkaline solution, further improves the corn's nutrient profile by increasing calcium and niacin and improving protein quality.

The intercropping of maize, beans, and pumpkins provided a highly productive cropping system that largely met the nutritional needs of the Haudenosaunee communities. The system's anchor, maize, is unique among cereals due to its tall, robust plant architecture that produces large quantities of nutrient-dense grain. Haudenosaunee farmers have taken advantage of these characteristics by adding beans and pumpkin to their corn fields (Table 1).

Table 1

Summary results of the global benefits of the «Three Sisters» model for intercropping and nutrients

Aspect	Findings
Global Intercropping [10; 11]	- Competitive balance between species is essential for performance. - Management factors impact competitiveness and productivity. A comprehensive analysis is needed to understand the relative performance of legumes and cereals. - Relative Seeding Time (RST) is crucial for competitiveness. - Cereals often have higher yields than legumes. - Sowing time, density, and nitrogen affect competitiveness. - Intercropping corn and soybeans enhances land conservation. - Simultaneous intercropping yields LER of 1.32, relay intercropping 1.25-1.46. - Intercropping increases total production or reduces land use.
Milpa Farming [3; 6]	- Milpa systems in WHG show higher productivity and nutrient adequacy than maize monocultures. - Corn-bean-potato, corn-potato, and corn-faba bean have the highest PNA values. - Milpa systems positively correlated with food security and nutrition.
Three Sisters Pest Protection	- The Three Sisters system protects maize from herbivores. - Increases direct chemical defense of maize. - Alters volatile organic compounds to deter herbivores.
Chinese Intercropping [8]	- Intercropping corn and field peas increases land use efficiency (LER 1.2-1.5). - Yield and water savings observed. - Polyethylene film mulch enhances yield and water use efficiency.
Nutritional Benefits Overview [12]	- Three Sisters provides high-quality protein and sufficient niacin. - Nixtamalization enhances corn's nutrient profile. - Three Sisters provides more energy and protein than monocultures. - Beans and pumpkins contribute to increased protein yield. - Pumpkin seeds rich in essential amino acids and vitamin A.

Strengths and Implications

Reviving 3SI through interdisciplinary research provides key benefits:

- Strengthening food sovereignty in underrepresented communities.
- Enhancing biodiversity and soil health.
- Supporting efficient land and water use.

However, challenges include:

- Conflicts between scientific measurements and Indigenous cultural values.
- Communication barriers in multidisciplinary teams.
- Land scarcity and social marginalization in regions like Guatemala, which hinder broad implementation [6].

Conclusions. The revival of Native American agricultural practices, such as the Three Sisters, as part of the struggle for indigenous food sovereignty is a relatively recent effort. The review's-controlled experiments and meta-analyses are well-distributed and well-designed, and the overall level of evidence can be rated as High for specific, narrowly defined questions (e.g., the specific benefits of intercropping the «Three sisters» on soil health or crop yields).

Intercropping is a well-established strategy for maximizing yield from a limited area, but mixed results have been obtained regarding water use efficiency. It is well known that increasing crop biodiversity plays a vital role in achieving ecologically based pest management (EBPM); however, the mechanism needs to be better understood.

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