Optimization of Traditional Crop Yields Through Experimental Design

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1 Abstract

The systematic literature review on the use of experimental designs in the optimization of traditional crops in Puno, Peru, reveals several key findings. The main objective was to identify the most used experimental designs, the geographical spaces where most experiments are conducted, and the crop groups that receive the most attention. Studies published between 2018 and 2024 were analyzed, using the Scopus database. The results show that classical experimental designs, such as factorial and completely randomized block, represent 33.3% of the reviewed studies, underlining their importance in the evaluation of treatments under controlled conditions. Furthermore, it is observed that Asia and Latin America are the most active regions in this research, with a particular focus on crops such as rice and potato, which are essential for local food security. Among the key findings, it is highlighted that although modern optimization methods are gaining ground, such as the use of algorithms and simulations, traditional approaches remain fundamental to improve agricultural production. The combination of classical and modern methods, together with validations in field trials, appears to be a promising strategy to maximize agricultural yields in diverse contexts. This review highlights the need to adapt experimental methodologies to specific agronomic conditions to achieve more efficient and sustainable agriculture. In conclusion, crop optimization requires a comprehensive approach that considers both traditional and innovative techniques to address current challenges in agricultural production.

Keywords Design of experiments (DOE), Agricultural optimization, Traditional crops, Crop yield, Sustainable agriculture.

2 Introduction

Importance of traditional crops, particularly potatoes, quinoa, and cañihua, in Puno's diet, food security, and economy. The potato, a staple in Puno's agricultural economy. Similarly, quinoa plays a vital role due to its resilience and nutritional value, "Quinoa is not only rich in proteins and carbohydrates, but also in bioactive substances like saponins, which have foaming, emulsifying properties and several health benefits"[1]. Despite its adaptability, monocropping quinoa can harm soil microbial diversity, essential for sustainable agriculture, "Quinoa cultivation in Andean regions highlights its ability to adapt to adverse conditions, though monocropping practices negatively affect soil microbial diversity"[2].

Native potato varieties, while integral to food security, have seen decreased cultivation due to limited industrial use, "The limited industrial use of native potato varieties has caused a decrease in cultivation, confining production to self-consumption and impacting food security"[3]. Cañihua, a protein-rich grain from the high-altitude Andes, thrives in Puno's semi-arid zones, "Cañihua originates in the Andes of southern Peru and Bolivia, has high protein content ($15-19\%$), and bioactive compounds like phenolics and carotenoids, beneficial for preventing chronic diseases"[4].

These traditional crops are central to Puno's sustainability, emphasizing the need for optimized cultivation practices.This approach is particularly useful in agriculture, where multiple factors (fertilizers, water, soil type) interact in complex ways.In agricultural experiments, optimizing interactions between factors such as fertilizers, water, and soil type is crucial for maximizing crop yield while minimizing resource use. Experiment optimization addresses these complexities. A common method involves response surface methodology (RSM), which balances multiple factors,"This study uses the desirability function approach to optimize ethanol concentration and profit, providing a robust solution to complex problems"[5]. Similarly, in agricultural applications, optimizing variables like water and soil conditions can be approached through experimental design,"An optimization approach was introduced to minimize testing effort by reducing configurations using meta-heuristic and evolutionary algorithms"[6].

Fractional experimental designs streamline processes, especially for factors sensitive to environmental conditions, like protein levels, "The optimization was achieved through fractional experimental design, considering operational parameters and protein sensitivity to environmental conditions"[7]. Balancing variables—such as temperature, speed, and material properties—can also be optimized, "The study used the hybrid Grey-TOPSIS method to balance trade-offs like tensile strength and surface roughness in multi-factorial designs"[8].

Pest control experiments highlight the need for understanding variable interactions, "Potato cyst nematode management involves studying soil types, climate, and resistant crops, showing how variables interact to optimize yield and pest control"[9]. Optimizing agricultural experiments in Puno involves considering various interrelated factors to ensure efficient and sustainable crop production, using methodologies applied in other complex fields. Optimizing traditional crop yields in Puno requires choosing the right DOE techniques to analyze factors like soil, water, nutrients, and farming methods, ensuring precise and practical results. Various DOE techniques have proven essential in optimizing complex systems, including agriculture. One such technique is factorial experiments, which evaluate multiple factors and their interactions, "The study utilizes factorial experiments and statistical analysis, focusing on the arcsine transformation. Two 2k designs accounted for weather, evaluating factors like operator experience, sealing speed, and extruder temperature. Effects on overheating and resistance were analyzed, optimizing the thermofusion process"[10].

A full factorial design can also evaluate key variables, ensuring all relevant factors are considered in the optimization process, "A 24 factorial design assessed flocculant dosage, settling time, and mixing time on harvesting efficiency. Optimal conditions included a dosage of 100 mg L-1 and 3 min of rapid mixing, significantly improving cost and process efficiencies""[11]. Similarly, fractional factorial designs combined with response surface methodology (RSM) help evaluate the interactions between factors, improving experimental efficiency, "Using fractional factorial design and RSM, this study optimized biomass production of Sphagnum species. Variables like pH, light intensity, and nutrients were evaluated, enhancing cultivation predictability and efficiency""[12]. Thus, applying appropriate DOE techniques, such as factorial and fractional designs, is critical for optimizing agricultural processes and understanding the complex interactions between factors influencing crop yield in Puno.

Farmers in Puno struggle to boost productivity due to harsh weather and limited resources. Extreme droughts and floods, combined with a lack of technology, expertise, and financial support, make it hard to improve farming practices like plant nutrition, post-harvest care, and agrochemical use. Climatic conditions play a primary role in agricultural productivity, impacting both crops and livestock, "The natural climatic conditions are the primary determinant of agricultural productivity. Factors like temperature, rainfall, and extreme events influence crop yields and livestock production, increasing costs and reducing income for farmers" [13] . Climate change further worsens food security and agricultural productivity, particularly for small-scale farmers who lack access to resources, "Climate change impacts food security through increasing temperatures, altered precipitation patterns, and extreme weather events. These changes reduce water availability and productivity, especially for farmers without access to resources like fertilizers or irrigation systems"[14].

Environmental shifts also directly affect biomass and food production, "Environmental conditions, especially changes in precipitation and temperature, directly impact biomass availability and productivity. Seasonal shifts, like those near Lake Titicaca, reduce local food production without external support"[15]. Thus, the combination of adverse climatic factors and insufficient technical and financial resources hampers farmers' ability to enhance crop yields in Puno. This research aims to improve the productivity of traditional crops in Puno, Peru, using Design of Experiments (DOE) techniques. It focuses on analyzing key factors like soil, water, climate, and farming methods to understand their impact on yields. The study also seeks to propose solutions to address challenges like changing weather patterns and limited technical resources, promoting more efficient and sustainable agriculture.

3 Methodology

Type of study

A systematic review of the scientific literature was conducted, covering both national (Peru) and international studies, using the electronic database Scopus. The objective of this review was to analyze works that focused on the optimization of experiments, particularly those employing design of experiments (DOE) applied to the process and performance of crops. This analysis concentrated on articles published between 2018 and 2024.

Techniques and Instruments

To organize and manage information effectively, the observation technique was used, allowing for direct and detailed data collection. This technique was supported by the methodological guidelines established by the Ibero-American Cochrane Center (2011), which provided a robust framework for critically and systematically evaluating the information.

The main tool for recording and managing the data was Google Sheets, which allowed for a clear organization of relevant indicators, such as: author, year of publication, type of study, crop investigated, sample size, experimental design method, and the performance optimization variable.

In a preliminary phase, the studies selected for the review had to meet certain criteria: 1) They had to be in English, with "optimization" as the central term; 2) They had to have been published between 2018 and 2024; 3) They had to address experimental research on crops within the field of biological sciences.

Literature Search

The strategy employed for the selection of studies involved conducting a thorough search in the electronic database Scopus, using the system provided by Concytec.

This search aimed to identify and compile a variety of relevant studies related to the research topic. The following keyword search was used "optimization, experiments, crops", as a whole, when searching in this way, the consequence was that, to obtain studies related to the research variable, first of all, no geographical area was determined, that is, no geographical limits were established. in the review (it was global).

During this initial phase, a total of 2,682 documents appeared. According to the preliminary search, the review was limited based on the following filters: a) The chosen language was English b) The selected documents were of the article type c) It was determined that the keywords used were experimental design, crops, optimization; The total filtered search was reduced to 36 studies.

According to the above, after a detailed search, all articles that did not meet the established criteria were eliminated through reading summaries and the methodology to assess whether experiments were used. It was evident that the majority of the documents did not primarily focus on the area of crops.

Finally, a total of 12 studies that were, in some way, related to the specific variable were selected. It is important to note that all the selected studies were open access, allowing for the correct retrieval of all of them.

The study selection process was carried out following the four phases of the flow chart known as PRISMA. Figure 1 shows the entire developed process, while Table 1 presents the selected studies chosen for review, providing key and general information about this selection, taking take into account the research topic, which is optimization of experiments. In addition, we created a file that can be viewed in Table 2 that collects key information from each study included in the research, by structuring the data into categories such as author, year, type of study, crop research. closed, sample size, experimental design and optimization. variables, I have created a tool that makes it easy to compare compare studies and identify common patterns or tendencies. In our analysis process, this sheet will be useful to quickly compare the methodologies used, the results obtained, maintained and the key variables that were optimized in the different studies. Furthermore, it will allow me to identify differences in the experimental designs with the performance variables in each study.

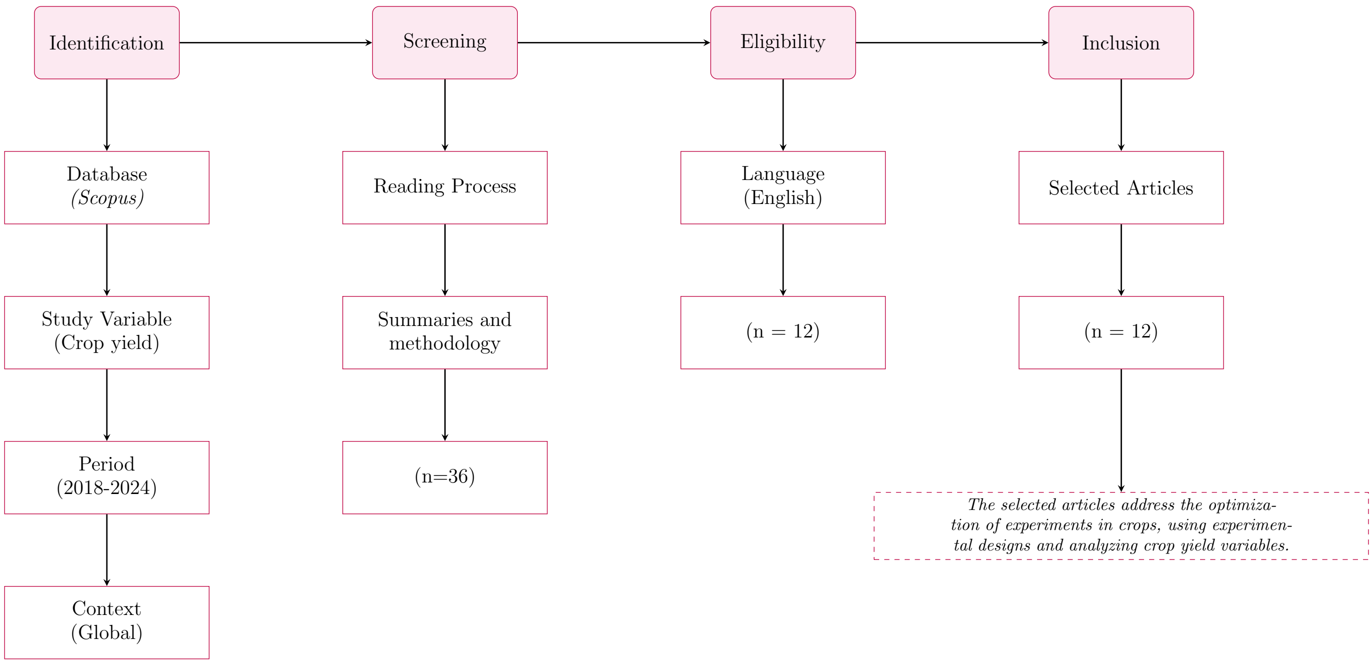

Figure 1: Prisma flowchart for the study information search.

N°	Author	Year	Country	Keywords
1	Moreira, B. R. Breitkreit0z, M. C. Simister, R. McQueen Mason, S. J. Gomez, L. D. & Rezende, C. A. [16]	2021	Brazil	Experimental design - Acid pretreatment - Alkali pretreatment - Rice husk - Silica
2	Qadeer Wahla, A. Iqbal, S. Anwar, S. Firdous, S. & Mueller, J. A.[17]	2018	Germany-Pakistan	Taguchi DOE - Diketo - metribuzin - experiment optimization - Desamino metribuzin
3	Ji, Y. Xu, Y. Sun, X. Hassan, M. A. Zhou, Y. Zou, H. & Li, Z.[18]	2024	China	Temperature - experiment - efficiency - Grain yield - Crops
4	Loewen, S. & Maxwell, B. D.[19]	2024	USA	Organic agriculture - Precision - On farm experimentation - Green manure - Optimization
5	Yang, X. Bol, R. Xia, l. Xu, C. Yuan, N. Xu, X. Wu, W. & Meng F.[20]	2024	China-Germany	Sustainable - Experimental design - Grain production - Nitrogen leaching
6	Sharafkhane, M. G. Ziaei, A. N. Naghedifar, S. M. Akbari, A. Verdi A.[21]	2024	USA	AquaCrop - Deficit irrigation - Optimization - PSO algorithm
7	Lu, Y. Ma, R. Gao, W. You, Y. Jiang, C. Zhang, Z. Kamran, M. Yang, X.[22]	2024	China	Rainfed agriculture - Optimization - Experiment - Dry matter yield - Water productivity
8	Maidana Palacios, S. S. Viana Ribeiro, J. W. Mapeli, N. C. Cremon, C. Mapeli, A. M.[23]	2024	Brazil	Scallion - Water Hyacinth - Homeopathy - Substrate - Agroecology
9	Anbazhagan, P. Halder, S.[24]	2024	India	borehole surveys - Automated algorithms - Signal processing - Experiments
10	Sandanña, P. Lizana, C. X. Pinochet D., Soratto R. P.[25]	2024	Chile-Brazil	Nitrogen Use Efficiency - Potato cultivation - Genotypic variation - Optimization
11	Calizaya, F., Gómez, L., Zegarra, J., Pozo, M., Mindani, C., Caira, C., Calizaya,[26]	2023	Perú	Sustainability - survey - experiments - potato and quinoa - highland
12	Nguyen, V. L., Luu, H. N., Phan, T. H. N., Nguyen, V. L., Chu, D. H., Bertero, D., Curti, N., McKeown, P. C., Spillane, C.[27]	2024	Vietnam	Genotype × Environment Interaction (GxE) - Water Stress Tolerance - Additive Main Effects and Multiplicative Interaction (AMMI) Model - Quinoa (Chenopodium quinoa)

Table 1: Characteristics of the systematized studies.

N°	Author	Year	Type of study	Crop studied	Number of treatments	Experimental design	Optimization variable
1	Moreira, B. R., Breitkreitz, M. C., Simister, R., McQueen-Mason, S. J., Gomez, L. D., & Rezende, C. A.[16]	2021	Experimental	Rice husk (*Oryza sativa*)	15 treatments	Fractional factorial design followed by central composite design (CCD)	Release of sugars (mg of glucose per gram of substrate)
2	Qadeer Wahla, A. Iqbal, S. Anwar, S. Firdous, S. & Mueller, J. A.[17]	2018	Experimental optimization	Potato (*Solanum tuberosum*)	12 treatments	Taguchi design (DOE)	Metribuzin degradation
3	Ji, Y. Xu, Y. Sun, X. Hassan, M. A. Zhou, Y. Zou, H. & Li, Z. [18]	2024	Experimental	Rice (*Oryza sativa L.*)	4 treatments	Randomized complete block design with subplots	Accumulated temperature efficiency and apparent radiation use efficiency (RUEA)
4	Loewen, S. & Maxwell, B. D.[19]	2024	Field precision experimentation	Wheat, oats, barley, hemp, and cover crops	5 treatments	OFPE	Seeding rate and net return
5	Yang, X. Bol, R. Xia, l. Xu, C. Yuan, N. Xu, X. Wu, W. & Meng F.[20]	2024	Long-term experimental	Winter wheat (*Triticum aestivum L.*) and summer maize (*Zea mays L.*)	3 treatments	Comparison of treatments (Control, Conventional, Optimized)	Nitrogen use efficiency (REN and NUE) and grain yield
6	Sharafkhane, M. G. Ziaei, A. N. Naghedifar, S. M. Akbari, A. Verdi A. [21]	2024	Experimental and simulation	Corn (*Zea mays L.*)	4 treatments	Irrigation optimization using AquaCrop and PSO algorithm	Water productivity (WPC, kg/m^3)
7	Lu, Y. Ma, R. Gao, W. You, Y. Jiang, C. Zhang, Z. Kamran, M. Yang, X.[22]	2024	Experimental	Forage maize (*Zea mays L.*)	9 treatments	Randomized complete block design with two factors	Dry biomass yield
8	Maidana Palacios, S. S. Viana Ribeiro, J. W. Mapeli, N. C. Cremon, C. Mapeli, A. M.[23]	2024	Experimental	Scallion (Allium fistulosum L.)	5 treatments	Completely randomized design (CRD)	Plant height, shoot diameter, and number of shoots
9	Anbazhagan, P. Halder, S.[24]	2024	Research study	Sugar cane crops	3 treatments	Algorithmic optimization	P and S wave detection
10	Sandana, P. Lizana, C. X., Pinochet, D., Soratto, R. P.[25]	2024	Experimental	Potato genotypes and nitrogen efficiency	15 treatments	Field trials	Nitrogen uptake and efficiency
11	Calizaya, F., Gómez, L., Zegarra, J., Pozo, M., Mindani, C., Caira, C., Calizaya, E.[26]	2023	Mixed study (surveys, interviews and observations)	Potato and quinoa	5 treatments	Sustainability indicators	General Sustainability Index (GSI)
12	Nguyen, V. L., Luu, H. N., Phan, T. H. N., Nguyen, V. L., Chu, D. H., Bertero, D., Curti, N., McKeown, P. C., Spillane, C.[27].	2024	Research article	Quinoa (Chenopodium quinoa)	58 treatments	Additive main effects and multiplicative interaction (AMMI)	Dry weight (DW)

Table 2: Sheet to contextualize the variables that characterize the studies.

4 Results

The studies conducted from 2018 to 2024 are described in Table 1. The 14 studies have used experimental designs and simulation studies to optimize agricultural yields through experimental design and computational simulation in traditional crops.

In general, the studies have addressed different crops. Figure 2 details how the studies have mainly addressed grains such as rice, corn, wheat and quinoa, highlighting their relevance in optimizing agricultural yields due to their economic and food importance. Tubers, represented by potatoes, have been the subject of studies focused on improving specific characteristics such as nutrient use efficiency. Crops grouped into other groups include vegetables such as shallots and cover crops, whose interest lies in variables associated with yield and sustainability. This focus on different types of traditional crops shows the diversity of objectives in the studies, from improving yield in basic grains to optimizing crops with less frequent study but with high agricultural value in specific contexts.

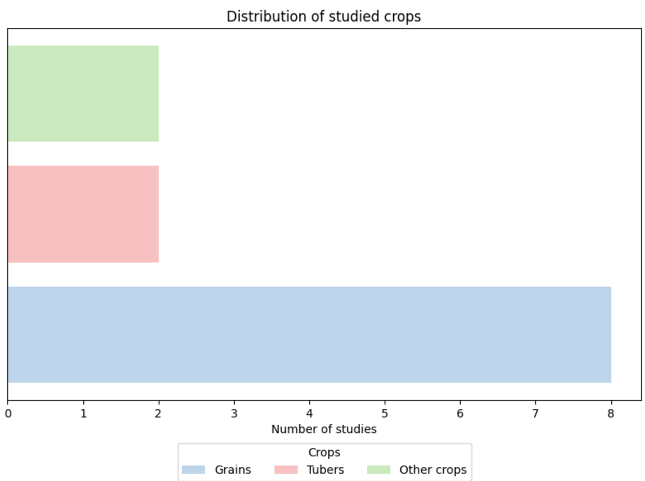

Figure 2: Crop groups studied in the review

The most widely used crop in the selected studies is rice (Oryza sativa L.), present in three investigations. This reflects its importance as one of the main staple grains, being the object of optimization for variables such as radiation use efficiency and agricultural yield.

In addition, experimental methods have been implemented. As specified in Figure 3, the analysis of the experimental designs used in the optimization of agricultural yields highlights a combination of classical and modern methodologies. Classic designs such as factorial and CRD (33.3%) remain as fundamental pillars to evaluate treatments under controlled conditions, while optimization models (33.3%), such as Taguchi and PSO algorithms, reflect a transition towards more advanced approaches that integrate simulation and algorithms to address complex variables such as water productivity and radiation use efficiency. Comparative field trials (25%) allow the validation of treatments under real conditions, and the rest of the studies (8.4%) focus on specific methodologies such as OFPE. This methodological diversity highlights how experimental designs, from traditional to innovative, complement each other to optimize traditional crops under different agronomic contexts.

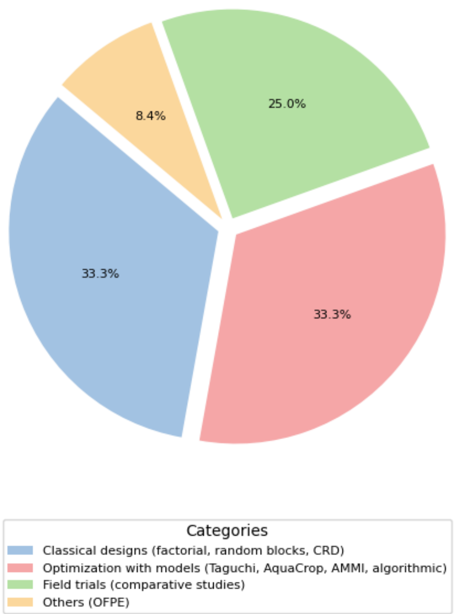

Figure 3: Most commonly used experimental designs in review studies

The most commonly used experimental designs in crops are classical designs, such as factorial, completely randomized blocks (CRD) and others, which represent 33.3% of the studies analyzed. This result indicates that, although modern methods such as algorithmic optimization are being adopted, traditional designs are still essential to evaluate treatments and improve yields in traditional crops.

Regarding the relevance of each region or global sector to carry out or apply the optimization of experiments, figure 4 shows the geographic distribution of studies related to the optimization of the yield of traditional crops through experimental designs.

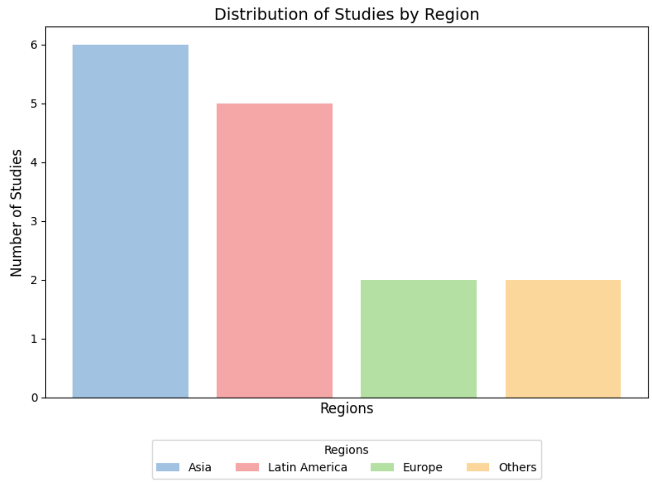

Figure 4: Geographical interest in using experimental design in crop optimization

The highest concentration of research was carried out in Asia (6 studies), which reflects the relevance of this region in the production of key crops such as rice and corn, which are essential for global food security. Latin America (5 studies) also stands out, possibly due to its agricultural diversity and the importance of crops such as potatoes and quinoa in local contexts. Europe and other regions show a lower representation (2 and 1 studies, respectively), suggesting that efforts in these areas are more distributed or focused on other types of research.

This overview shows how regions with a high dependence on traditional crops are leading optimization efforts, with a focus on maximizing yields through experimental designs adapted to local conditions.

The data were described in tables and organized in frequencies (f), allowing a descriptive quantification of the studies according to crop type, experimental design and optimized variable.

5 Discussion

Optimizing agricultural yields through experimental design has a topic of growing interest between 2018 and 2024. The studies reviewed in this article show significant variability in the experimental methods and designs employed, reflecting an effort to adapt methodologies to the specific agronomic conditions of each crop. In general, classical experimental designs, such as factorial and completely randomized blocks (CRD), continue to be the most widely used, representing 33.3% of the studies analyzed, underlining their importance as a fundamental tool in the evaluation of treatments under controlled conditions. This finding is aligned with previous works indicating that classical designs remain essential due to their simplicity and ability to establish clear relationships between variables (Canales-Gutiérrez & Gutiérrez-Flores, 2021). Despite the rise of modern techniques, such as algorithmic optimization and the use of models like Taguchi or AquaCrop (Sharafkhane et al., 2024), classical approaches persist as a reliable option, especially in situations where direct control of variables is crucial.

On the other hand, more recent studies have adopted algorithmic optimization and simulation methods, which represent another 33.3% of the studies analyzed. These approaches, such as the Taguchi design to optimize metribuzin degradation in crops (Wahla et al., 2018) or the use of the PSO algorithm in irrigation scheduling for corn (Sharafkhane et al., 2024), reflect a trend towards the integration of advanced technologies that allow addressing the complexity of agronomic variables, such as water or nutrient use efficiency. This is consistent with the literature showing that computational optimization is taking a crucial role in improving agricultural productivity (Qadeer Wahla et al., 2018).

Comparative field trials, representing 25% of the studies, are essential to validate treatments under real-world conditions. These studies allow to confirm the results obtained in the laboratory or under controlled conditions, and are essential for the practical application of the proposed optimizations (Loewen & Maxwell, 2024). The fact that a quarter of the studies use these approaches also underlines the importance of conducting field trials to ensure that the proposed improvements are viable under real-world growing conditions.

A key feature in the organization of the studies is the geographical distribution, where it is observed that most of the studies come from Asia and Latin America (Yang et al., 2024). This is not surprising, given that regions such as Southeast Asia, where rice is grown on a large scale, and Latin America, with crops such as potato and quinoa, are investing significant resources in traditional crop optimization. This distribution also reflects the high dependence of these crops on food security and the local economy (Ji et al., 2024).

In conclusion, although classical designs continue to be predominant in traditional crop optimization research, modern optimization methods such as algorithms and simulation are gaining ground. Studies reflect a trend towards an integration of traditional and advanced approaches, allowing for a more comprehensive and accurate assessment of crop yields. Combining these methods, together with the validation of results in field trials, could be the key to improving agricultural yields in different geographical and productive contexts.

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