Optimization of Traditional Crop Yields Through Experimental Design in Puno, Peru

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1 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.

2 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 gather a variety of relevant studies related to the research topic. Consequently, to obtain studies related to the research variable, first, no geographical area was determined, meaning that 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 narrowed down based on the following filters: a) The chosen language was English b) The selected documents were of the article type c) The keywords used were determined to be 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 14 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.

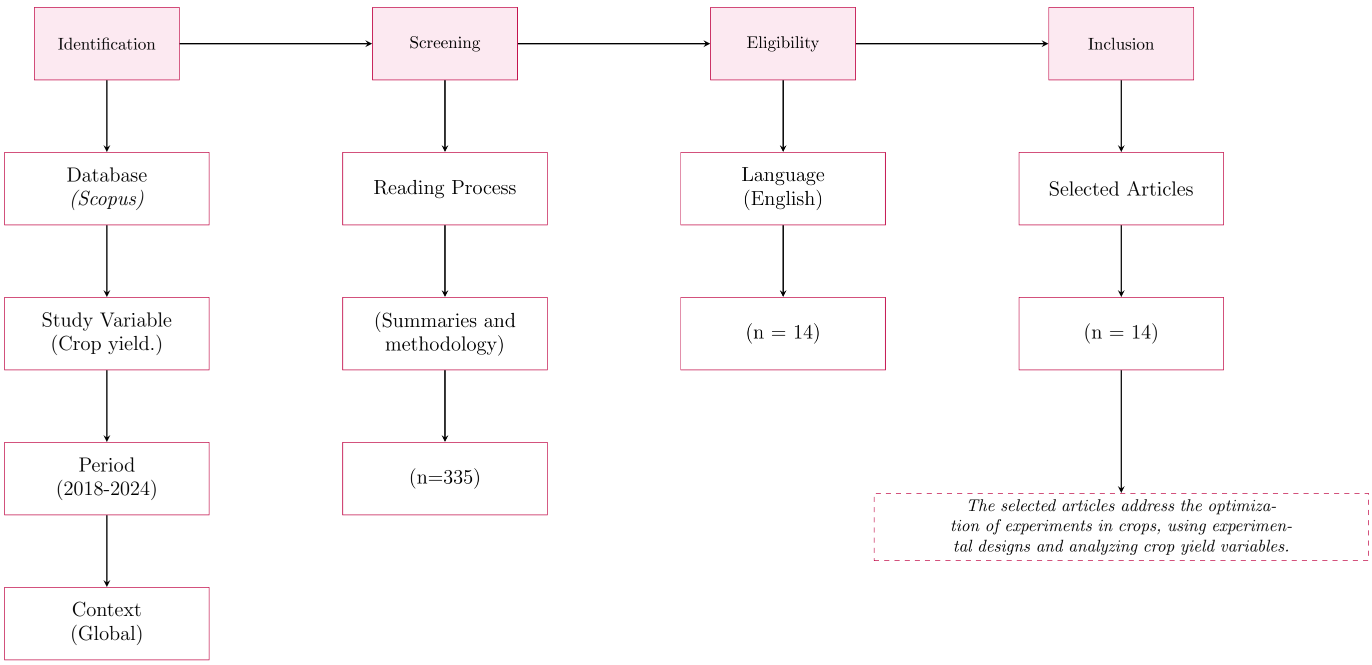

Figure 1: Prisma flowchart for the study information search.

N°	Author	Year	Country	Keywords
1	Moreira, B. R. Breitkreit0z, M. C. Simister, R. McQueen Mason, S. J. Gomez, L. D. & Rezende, C. A.	2021	Brazil	Experimental design - Acid pretreatment - Alkali pretreatment - Rice husk - Silica
2	Qadeer Wahla, A. Iqbal, S. Anwar, S. Firdous, S. & Mueller, J. A.	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.	2024	China	Temperature - experiment - efficiency - Grain yield - Crops
4	Loewen, S. & Maxwell, B. D.	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.	2024	China-Germany	Sustainable - Experimental design - Grain production - Nitrogen leaching
6	Sharafkhane, M. G. Ziaei, A. N. Naghedifar, S. M. Akbari, A. Verdi A.	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.	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.	2024	Brazil	Scallion - Water Hyacinth - Homeopathy - Substrate - Agroecology
9	Anbazhagan, P. Halder, S.	2024	India	borehole surveys - Automated algorithms - Signal processing - Experiments
10	Sandana, P. Lizana, C. X. Pinochet D., Soratto R. P.	2024	Chile-Brazil	Nitrogen Use Efficiency - Potato cultivation - Genotypic variation - Optimization
11	Neto, A. S. Wainaina, S. Chandolias, K. Piatek, P. Taherzadeh M. J.	2024	Sweden	Syngas fermentation - Biofuels - Acetogenic bacteria - Process optimization
12	Haloui, D. Oufaska, K. Oudani, M. Yassini, K. E. Belhadi, A. Kamble, S.	2024	Morocco-France	Sustainability - Multi-objective - Environmental impact - Optimization methods
13	Koukoulakis, P. H. Kyritsis, S. S. Zhu, G. Kalavrouziotis I. K.	2024	Greece, China	DSS tool - Wastewater reuse - Biosolids - Soil optimization
14	Yu, N. Wang, C. Chen, H. Kong W.	2024	China	Magnetotelluric inversion - Crops - Deep learning - Experiments

Table 1: Characteristics of the systematized studies[16],[17],[18],[19],[20],[21],[22],[23],[24],[25],[26],[27],[28],[29]

N°	Author	Year	Type of study	Crop studied	Sample size	Experimental design	Optimization variable
1	Moreira, B. R., Breitkreitz, M. C., Simister, R., McQueen-Mason, S. J., Gomez, L. D., & Rezende, C. A.	2021	Experimental	Rice husk (*Oryza sativa*)	Non-explicit	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.	2018	Experimental optimization	Potato (*Solanum tuberosum*)	Non-explicit	Taguchi design (DOE)	Metribuzin degradation
3	Ji, Y. Xu, Y. Sun, X. Hassan, M. A. Zhou, Y. Zou, H. & Li, Z.	2024	Experimental	Rice (*Oryza sativa L.*)	Non-explicit	Randomized complete block design with subplots	Accumulated temperature efficiency and apparent radiation use efficiency (RUEA)
4	Loewen, S. & Maxwell, B. D.	2024	Field precision experimentation	Wheat, oats, barley, hemp, and cover crops	11 years-site across 5 farms	OFPE	Seeding rate and net return
5	Yang, X. Bol, R. Xia, l. Xu, C. Yuan, N. Xu, X. Wu, W. & Meng F.	2024	Long-term experimental	Winter wheat (*Triticum aestivum L.*) and summer maize (*Zea mays L.*)	12 plots (450 m² each)	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.	2024	Experimental and simulation	Corn (*Zea mays L.*)	700 m² plot within 20 ha field	Irrigation optimization using AquaCrop and PSO algorithm	Water productivity (WPC, kg/m³)
7	Lu, Y. Ma, R. Gao, W. You, Y. Jiang, C. Zhang, Z. Kamran, M. Yang, X.	2024	Experimental	Forage maize (*Zea mays L.*)	2 years (24 m² treatment)	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.	2024	Experimental	Scallion (Allium fistulosum L.)	30 plots	Completely randomized design (CRD)	Plant height, shoot diameter, and number of shoots
9	Anbazhagan, P. Halder, S.	2024	Research study	Seismic wave analysis	Not specified	Algorithmic optimization	P and S wave detection
10	Sandana, P. Lizana, C. X., Pinochet, D., Soratto, R. P.	2024	Experimental	Potato genotypes and nitrogen efficiency	15 genotypes	Field trials	Nitrogen uptake and efficiency
11	Neto, A. S. Wainaina, S. Chandolias, K. Piatek, P. Taherzadeh, M. J.	2024	Review article	Syngas fermentation	Not applicable	Biological conversion	Renewable biofuels
12	Haloui, D. Oufaska, K., Oudani, M. Yassini, K. E. Belhadi, A. Kamble, S.	2024	Research study	Urban farming optimization	Not specified	Multi-objective decision-making	Sustainable location selection
13	Koukoulakis, P. H. Kyritsis, S. S. Zhu, G. Kalavrouziotis, I. K.	2024	Research study	Wastewater and biosolids reuse	Not specified	DSS for sustainable agriculture	Soil fertility, water reuse, and pollution prevention
14	Yu, N. Wang, C. Chen, H., Kong, W.	2024	Research study	Magnetotelluric inversion	200,000 samples	Improved DenseNet	Subsurface resistivity mapping

Table 2: Sheet to contextualize the variables that characterize the studies [16],[17],[18],[19],[20],[21],[22],[23],[24],[25],[26],[27],[28],[29]

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