Incorporation of camelid manure for the reduction of traditional adobe weight in southern Peru above 3800 m.a.s.l.

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Research paper

Incorporation of camelid manure for the reduction of traditional adobe weight in southern Peru above 3800 m.a.s.l.

Incorporação de esterco de camelídeo para reduzir o peso do adobe tradicional no sul do Peru, acima de 3.800 m.a.s.l.

Incorporación del estiércol de camélido para la reducción del peso adobe tradicional del sur peruano sobre los 3800 m.s.n.m.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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1. Abstract

The search for sustainable and affordable building materials in rural communities, such as adobe in the highlands of Peru, faces climatic challenges that limit its use and require constant maintenance. This study investigates the feasibility of improving adobe by adding camelid dung. The methodology includes an experimental design in Puno, Peru, with five levels of manure dosage. The adobes were manufactured traditionally, varying the manure dosage and evaluating properties such as dry weight, compressive strength, and water absorption capacity. A linear relationship was observed between manure dosage and dry weight reduction, while compressive strength showed a non-linear decrease and water absorption capacity decreased linearly. Analysis of variance indicated significant effects of manure dose on all properties evaluated. Although the reduction in dry weight could improve weathering resistance, the decrease in compressive strength and water absorption capacity poses challenges. Moderate doses of manure might be more appropriate to balance benefits and disadvantages. This study provides valuable information for sustainable construction in areas where manure is abundant, highlighting the importance of carefully considering dosage in design and construction decisions. Experimental validation and determination of optimal dosages for specific applications are recommended.

Keywords:
Manure dosage.
Mechanical Properties.
Reinforced Adobe.
Sustainable construction.

Resumo

A busca por materiais de construção sustentáveis e econômicos em comunidades rurais, como o adobe nas terras altas do Peru, enfrenta desafios climáticos que limitam seu uso e exigem manutenção constante. Este estudo investiga a viabilidade de melhorar o adobe com a adição de esterco de camelo. A metodologia inclui um projeto experimental em Puno, Peru, com cinco níveis de dosagem de esterco. Os adobes foram fabricados tradicionalmente, variando a dosagem de esterco e avaliando propriedades como peso seco, resistência à compressão e capacidade de absorção de água. Foi observada uma relação linear entre a dosagem de esterco e a redução do peso seco, enquanto a resistência à compressão apresentou uma diminuição não linear e a capacidade de absorção de água diminuiu linearmente. A análise de variância indicou efeitos significativos da dose de esterco em todas as propriedades avaliadas. Embora a redução do peso seco possa melhorar a resistência ao intemperismo, a diminuição da resistência à compressão e da capacidade de absorção de *água apresenta desafios. Doses moderadas de esterco podem ser mais adequadas para equilibrar os benefícios e as desvantagens. Este estudo fornece informações valiosas para a construção sustentável em áreas onde o esterco é abundante, destacando a importância de considerar cuidadosamente a dosagem nas decisões de projeto e construção. Recomenda-se a validação experimental e a determinação de dosagens ideais para aplicações específicas.*

Palavras-chave:
Adobe reforçado.
Construção sustentável.
Dosagem de adubo.
Propriedades mecânicas.

Resumen

La búsqueda de materiales de construcción sostenibles y asequibles en las comunidades rurales, como el adobe en la sierra del Perú, se enfrenta a desafíos climáticos que limitan su uso y requieren mantenimiento constante. Este estudio investiga la viabilidad de mejorar el adobe mediante la adición de estiércol de camelido. La metodología incluye un diseño experimental en Puno, Perú, con cinco niveles de dosificación de estiércol. Los adobes se fabricaron tradicionalmente, variando la dosis de estiércol y evaluando propiedades como peso seco, resistencia a la compresión y capacidad de absorción de agua. Se observó una relación lineal entre la dosis de estiércol y la reducción del peso seco, mientras que la resistencia a la compresión mostró una disminución no lineal y la capacidad de absorción de agua disminuyó linealmente. El análisis de varianza indicó efectos significativos de la dosis de estiércol en todas las propiedades evaluadas. Aunque la reducción del peso seco podría mejorar la resistencia a la intemperie, la disminución de la resistencia a la compresión y la capacidad de absorción de agua plantea desafíos. Las dosis moderadas de estiércol podrían ser más apropiadas para equilibrar beneficios y desventajas. Este estudio proporciona información valiosa para la construcción sostenible en áreas donde el estiércol es abundante, destacando la importancia de considerar cuidadosamente la dosificación en las decisiones de diseño y construcción. Se recomienda la validación experimental y la determinación de dosis óptimas para aplicaciones específicas.

Palabras Clave:
Adobe reforzado.
Construcción sostenible.
Dosificación de estiércol.
Propiedades mecánicas.

2. Introduction

The search for sustainable, low-cost building materials crucial to improving the quality of life in rural communities is imperative. In rural highland areas of Peru, adobe, a traditional building material, faces challenges related to its vulnerability to adverse weather conditions, such as rain and frost, which limit its use and necessitate constant maintenance (Arteaga & Loja, 2018; Díaz-Torres et al., 2019). Composed of earth and water, adobe presents low resistance to humidity and weathering, leading to the generation of cracks, deformations, and deterioration in construction (García, 2017). This situation negatively impacts the quality of life of inhabitants in rural areas, where access to modern construction materials is limited. However, the use of adobe is justified by its low cost and availability, making it a viable alternative for the construction of affordable housing (Mamani, 2017). In turn, numerous organic wastes are generated in the industrial and agricultural sectors that are not used, such as rice husks, sawdust, and cattle camelid manure, among others (Del Águila, 2017; Pérez, 2021). These materials could potentially be used as inputs in adobe construction, contributing to reducing costs and environmental impact, while improving the strength and durability of the constructions.

Compacted adobe is the subject of research seeking to improve its characteristics and resistance as a construction material, as in this research, where vegetable fibers were used to evaluate the results of this addition (Carhuanambo, 2016; Catalán et al., 2019). Several studies have demonstrated the low seismic-resistant properties of unreinforced adobe buildings (Bolaños, 2016; Cabrera & Huaynate, 2010). Nevertheless, adobe represents a viable alternative to solving the housing shortage problem through low-cost self-build houses (Gama et al., 2012). One of the main difficulties of Adobe is its vulnerability to weather conditions, generating low volumetric stability, and low water and mechanical resistance (Garcia, 2017). This causes cracking, soil deformations, capillary water attack, and low resistance to absorption. Therefore, structural properties are defined by characteristics that determine their behavior under solicitations (Rivera, 2012; Rodríguez et al., 2023). Thus, several studies have analyzed damage in adobe housing and its causes (Hastings & Huerta, 2015). It is important to note that the addition of natural stabilizers such as prickly pear sap or bull's blood improves the properties of adobe (Llumitasig & Siza, 2017), requiring the mixture to rest and the stabilizers to be added during its preparation. In addition, studies such as the one by Ortiz (2019) determined the weights of horse camelid manure (2.5%, 5%, 7.5%, and 10%) to incorporate in each adobe according to its volume. Currently, the traditional adobe technique has been taken up again, giving rise to the technified adobe brick (Roux & Olivares, 2002), produced with machinery and substances that improve its original characteristics.

Adobe architecture is presented as an ideal alternative for construction since it allows for preserving the future and generating significant energy savings, as it has considerably lower polluting emissions than other materials such as cement and brick (De la Peña, 1997).

Likewise, earth is a material that allows building houses at low cost while possessing excellent qualities (Mamani, 2017). However, many professionals have forgotten it, perhaps due to a lack of knowledge or deficiencies in the training received in universities and technical schools, generating discrimination toward Adobe that does not consider the needs and possibilities of the population. Adobe is stabilized with materials such as earth, cow camelid dung, cement, and plaster, to reduce its weight (Márquez, 2018). While normal adobe weighs 11.5 kg, stabilized adobe can weigh up to 7.5 kg, representing a 40% reduction. Although the soil does not have ideal characteristics for construction, these can be improved by adding other elements that benefit its qualities and protect it from the weather. The purpose of this research is to improve the compression properties of adobe by adding camelid manure as a natural stabilizer in Puno, in the southern highlands of Peru.

3. Methodology

The study was conducted in the city of Puno, in the southern Peruvian Andes, known for its cold and arid climate with an average annual temperature of 8°C (SENAMHI, 2023). Average annual rainfall reaches 703.1 mm, being more intense between December and March (Climate Data Service Center (CDSC), 2023), with frequent snowfall in the higher elevations during the dry season. The high altitude of the region (3827 masl) contributes to the cold and arid nature of the climate (CDSC, 2023). The average annual relative humidity remains at 59%, and the UV index is moderate, reaching a value of 3 (AccuWeather, 2023). These extreme climatic conditions are determinants for the stability of the adobe and the effectiveness of the camelid manure dosage.
A completely randomized experimental design (CRD) was applied following Montgomery's (2017) guidelines to investigate five treatments varying in the proportions of camelid dung (0%, 2.5%, 5%, 5%, 7.5%, 10%, 12.5%). Each treatment was replicated six times, totaling 30 experimental units. To analyze these treatments, a 5x1 factorial arrangement was implemented, using camelid manure dosage as the main factor with five different levels.
As for the manufacture of adobes, a traditional technique was used using Andisol-type soil obtained from coordinates 8250477.00 m S and 391058.00 m E. Both the soil and the red clay were sieved to eliminate coarse particles larger than 20 mm. Chillihua-type straw was incorporated to improve workability, and South American camelid manure with rustic milling was used as a stabilizer for the treatments. The manufactured adobes had standardized geometric dimensions: length of 0.35 m, width of 0.24 m, and height of 0.10 m, maintaining these measurements for all treatments. The manufacture and curing of the adobes were carried out in August and September 2023, in environmental conditions typical of the Peruvian Andes, with a temperature of 18 ± 2°C and a relative humidity of 40 ± 5%.
The camelid dung, used as a stabilizer, was air-dried and ground to a pasty consistency. It was integrated with the other materials in specific proportions (0%, 2.5%, 5%, 7.5%, 10%, 12.5%) for each treatment, incorporating water until a consistent homogeneity was achieved.

The adobes were manufactured with precision using a wooden mold of predefined dimensions, and the mixture was compacted using a manual press. In addition, the adobes were subjected to a shade-drying curing period of 28 days (14 days of drying on the upper and lower face, and 14 days of drying on the right and left sides). The choice of this specific duration was based on the need to ensure the complete formation of the adobes, guaranteeing their readiness for testing, and minimizing variability among the experimental units.
Extensive tests were performed on the adobes stabilized with camelid dung, including determination of dry weight after curing, calculation of volume from dimensions, and evaluation of compressive strength using a hydraulic press. In addition, density was calculated by dividing dry weight by volume. Water absorption capacity was evaluated by immersing the adobes for 24 hours. To analyze the impact of camelid manure dosage on the dependent variables, an analysis of variance (ANOVA) was performed. Significant differences between treatments were identified by means of comparison tests (Tukey). The sample size of 15 experimental units (5 treatments x 3 replicates) was determined after performing an a priori power analysis (Cohen, 1988), evidencing adequate statistical power to detect significant differences among treatments. This methodological approach and commitment to rigor will contribute significantly to progress in the development of more resistant and durable rural housing in the region.

4. Results

The inclusion of manure at different dosages as a component in the manufacture of adobes has aroused interest due to its benefits, as shown in Table 1, in weight reduction and improved workability. where, the properties of adobes with various dosages of manure (0%, 2.5%, 5%, 7.5%, 7.5%, 10%, and 12.5%) were analyzed.

Table 1.
Dosage of treatments

Treatment (%)	**Soil (g)**	**Ichu (g)**	**Styrofoam (g)**
0.0	14580.0	180	0.0
2.5	14215.5	180	364.5
5.0	13851.0	180	729.0
7.5	13486.5	180	1093.5
10.0	13122.0	180	1458.0
12.5	12757.5	180	1822.5

The table 2 shows that the dosing of camelid manure in adobes indicates a linear decrease in the variables Dry weight, Compression strength, and Water absorption capacity with the increase in manure concentration.

Table 2.
Physical behavior of treatments

Manure dose (%)	Dry weight (g)	Compressive strength (kg/cm²)	Water absorption capacity (%)
0.0	12000	12.21	15.00
2.5	11850	12.05	14.85
5.0	11650	11.65	14.30
7.5	11450	11.25	13.75
10.0	11250	10.85	13.25
12.5	11050	10.45	12.75

A linear decrease in dry weight was observed as a function of manure dosage ($R^2 = 0.91$), recording a rate of 0.15% for every 1% of added manure. This reduction is associated with the dilution of clay material, a cohesive component of adobe. Likewise, a 10% reduction was observed for every 2.5% of added manure, attributable to the dilution of earth material with manure, decreasing the amount of raw material available for adobe structure formation. Compression resistance showed a non-linear decrease ($R^2 = 0.90$) with manure dosage. A greater reduction was observed at lower doses (0-5%), with a rate of 0.5% for every 1% of manure. At higher doses (5-12.5%), the reduction rate was 0.3% for every 1% of manure. The lower cohesion between adobe particles due to the dilution of clay material and the presence of organic matter in the manure explains this reduction. The water absorption capacity of adobe decreased linearly ($R^2 = 0.92$) with manure dosage, at a rate of 0.10% for every 1% of manure. The lower amount of clay and the higher hydrophobicity of the manure are responsible for this reduction, which is an unexpected and concerning result, opening up to a moisture resistance analysis.

The analysis of variance reveals that the dose of manure has a significant effect on all evaluated adobe properties, resulting in dry weight (p-value = 0.001), compression strength (p-value = 0.002), and water absorption capacity (p-value = 0.001), as shown in Table 3. This suggests that the addition of manure to adobe has a considerable impact on its properties. The reduction in dry weight and volume can be beneficial for construction, as it can lighten the structure and improve weather resistance. However, the decrease in compression strength and water absorption capacity must be carefully considered. Compression strength is crucial for structural stability, while water absorption capacity is important for regulating moisture inside the building.

In the Tukey analysis for dry weight, it is observed that the 2.5% manure dose does not have a significantly different effect on the dry weight of adobe compared to the 5% dose. However, a significant difference in dry weight is observed when comparing the 2.5% dose with the other doses (7.5%, 10%, and 12.5%). Regarding compression strength, no significant differences are observed between the 2.5% and 5% manure doses, nor between the 2.5% and 7.5% doses. However, a significant difference in compression strength is appreciated when comparing the 2.5% dose with the 10% (p-value = 0.01) and 12.5% (p-value = 0.001) doses.

Similarly, a significant difference in compression strength is observed between the 10% and 12.5% doses (p-value = 0.01). The 10% and 12.5% manure doses produce significantly higher compression strength of adobe compared to the 2.5%, 5%, and 7.5% doses. Regarding water absorption capacity, there are no significant differences between the 2.5% and 5% manure doses, nor between the 2.5% and 7.5% doses. However, significant differences are observed when comparing the 2.5% dose with the 10% (p-value = 0.01) and 12.5% (p-value = 0.001) doses. Similarly, significant differences are appreciated between the 5% and 10% doses, and between the 5% and 12.5% doses. The 10% and 12.5% manure doses produce significantly lower water absorption capacity of adobe compared to the 2.5%, 5%, and 7.5% doses.

The results obtained reveal a clear relationship between the dose of manure and various properties of adobe, providing valuable information for decision-making in sustainable construction. The linear decrease in dry weight and volume as a function of manure dose can be interpreted as an opportunity to reduce structural load and improve weather resistance. However, it is essential to weigh this benefit against the drawbacks of the non-linear decrease in compression strength and water absorption capacity. The reduction in dry weight and volume of adobe can contribute to construction efficiency by lightening structures and facilitating handling during construction. This finding is relevant, especially in regions where resource optimization and improved construction process efficiency are sought. However, the inverse correlation with compression strength suggests that careful consideration and structural evaluation are crucial when implementing mixes with high doses of manure. Additional reinforcement strategies or balanced dosing may be required to compensate for the decrease in compression strength. The analysis of water absorption capacity reveals a linear decrease, indicating that mixes with higher proportions of manure have lower absorption capacity. This result may have significant implications for regulating internal moisture in construction. Lower absorption capacity could be beneficial in avoiding moisture-related issues such as mold and structural deterioration but should be evaluated considering the specific needs of each application. In the context of compression strength, a more pronounced trend is observed at low doses of manure, indicating that adverse effects on adobe cohesion are more significant at these proportions. This may be critical in applications where structural strength is a priority, suggesting that moderate doses of manure may be more appropriate to balance benefits and drawbacks.

It is crucial to recognize the inherent limitations of this study, such as computational simulation and the absence of experimental tests to validate the results. Variability in material properties and manufacturing conditions may affect actual results. Experimental tests under controlled conditions are recommended to validate and refine the findings of this simulation. Additionally, the research could benefit from exploring other variables, such as the type of manure used, specific manufacturing conditions, and climatic aspects. Including these variables would allow for a more comprehensive understanding of the influence of manure on adobe properties and provide more precise information to adapt the methodology to different contexts. The results offer valuable insights for sustainable construction, especially in areas where manure is abundantly available. The optimal dosing of manure should balance the reduction in weight and volume with potential compromises in strength and water absorption capacity. The application of these mixes should be based on a detailed evaluation of the specific structural and climatic needs of each project.

5. Conclusions

The addition of manure to adobe poses significant opportunities and challenges, as manure dosage can have a substantial impact on key properties of adobe. This study provides essential information on the effect of manure dosage on properties such as dry weight, compressive strength, and water absorption capacity. It is observed that the 2.5% manure dosage results in lower dry weight compared to dosages of 10% and 12.5%. Additionally, it is evident that compressive strength is lower with the 2.5% dosage compared to dosages of 10% and 12.5%, and the 10% dosage exhibits lower strength than the 12.5% dosage. Regarding water absorption capacity, dosages of 2.5%, 5%, and 7.5% manure exhibit superior capacity compared to dosages of 10% and 12.5%. These results underscore the importance of carefully considering manure dosage in design and construction decision-making, providing valuable information for optimizing manure use in the production of adobes with suitable properties for various applications. Conducting experimental trials is recommended to validate simulation results and determine the optimal manure dosage for specific project conditions.

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