

Impact of Solar Drying Temperatures on Total Polyphenols and Antioxidant Activity of Bee Pollen from the Mantaro Valley, Peru

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Abstract Bee pollen is a functional food highly valued for its content of bioactive compounds, especially polyphenols, known for their antioxidant properties and their role in preventing oxidative stress and chronic non-communicable diseases. However, during processing—particularly the drying stage—these compounds can be affected. This study aimed to evaluate the influence of different solar drying temperatures (40, 50, and 60 °C) on the total polyphenol content and antioxidant capacity of bee pollen collected in the Tarma region, Junín, Peru. A completely randomized experimental design was applied using analysis of variance (ANOVA), followed by Tukey's test to determine significant differences among treatments. The samples were dehydrated in an automated solar dryer under controlled temperature and humidity conditions. Polyphenols were determined using the Folin-Ciocalteu method, and antioxidant activity was assessed using the DPPH assay. The results showed a significant increase ($p < 0.05$) in both polyphenol content and antioxidant capacity as the drying temperature increased, reaching the highest values at 60 °C. These findings suggest that, contrary to some technical regulations limiting drying temperatures to 45 °C, higher temperatures may favor the release of bound polyphenols or induce structural changes in the pollen matrix that enhance their bioavailability. As a limitation,

this study only evaluated polyphenols and antioxidant activity, without considering other relevant bioactive compounds. The practical implications of this research include the optimization of solar drying processes under controlled conditions to preserve and even enhance the functional properties of bee pollen, which is beneficial for both the food industry and the nutraceutical sector. Furthermore, it provides evidence that could support the revision and updating of technical standards related to pollen processing.

Keywords Solar Drying, Polyphenols, Antioxidant Capacity, Drying Temperature, Bee Pollen

1. Introduction

Bee pollen is recognized as a functional food due to its rich composition of nutrients and bioactive compounds, including polyphenols and antioxidants. These compounds are essential for human health, as they possess antioxidant properties that help combat oxidative stress and may contribute to the prevention of various diseases [1].

The quality of bee pollen can be affected by several

factors, with drying temperature being one of the most critical. Solar drying is a commonly used technique for preserving pollen, but the temperature at which this process is carried out can significantly influence the retention of its bioactive properties. Solar drying of pollen also affects its thermodynamic characteristics and structure [2].

Many studies have focused on other food products, leaving aside the specific influence of solar drying temperature on pollen [3].

Furthermore, the variability in the results of previous studies suggests that further research is needed to understand how different drying temperatures affect the polyphenol content and antioxidant capacity of bee pollen [4].

The research of Zuluaga et al. [5] provides valuable insights into how drying operations for bee pollen processing can be optimized, balancing the need for microbiological safety with the preservation of key nutritional and sensory characteristics. While research has also been conducted on the effects of drying on various foods, there are still gaps in our knowledge of the specific impact of controlled solar drying on bee pollen, particularly in Andean contexts such as Tarma. Therefore, Zuluaga [5] suggests that adjusting thermal conditions for pollen drying can balance microbiological safety with the preservation of key nutritional and sensory attributes.

This study aims to address the effect of solar drying temperatures (40, 50, and 60 °C) on bee pollen, thus contributing to the existing knowledge on optimizing its processing. This study seeks to fill the thematic gaps identified in the literature and provide valuable information that can be used to improve pollen drying and preservation practices, thus ensuring the preservation of its functional and nutritional properties.

According to Keskin and Özkök [6], drying is used for bee pollen because it minimizes damage to its bioactive components. They also investigated the α -amylase inhibition properties of bee pollen and bee bread (perga). Their studies focused on the impact of drying techniques on the chemical composition and volatile components of bee pollen. The research highlights the importance of processing methodologies in preserving the beneficial properties of bee pollen.

Kim et al. [7] investigate the optimization of bee pollen extraction. It uses response surface methodology to correlate extraction conditions with anti-melanogenesis activity, antioxidant activity, and phenolic content. The study sought to maximize the antioxidant and tyrosinase inhibitory activity of bee pollen by exploring factors such as extraction solvent and extraction time. The response surface methodology allows for the identification of the optimal conditions for extracting the desired bioactive compounds from bee pollen, which is relevant for research into its applications in health.

The "Artisanal Technical Standard for Honey and Bee Products" (Version 2) of the Government of Navarre, from 2023, establishes guidelines for the production of honey

and bee products. This regulation, mentioned in Regional Decree 103/1994, covers general aspects and relates to the contracting of honey analysis services for beekeepers. The document details requirements for the preparation and presentation of these products, guaranteeing their quality and safety [8].

Bee pollen is recognized as a functional food of high nutritional value, composed of a complex matrix of macronutrients such as carbohydrates (40–60%), proteins (20–60%) and lipids (1–32%), in addition to essential micronutrients such as vitamins, minerals, amino acids and phenolic compounds with high antioxidant capacity [9].

This profile gives it therapeutic properties such as anti-inflammatory, antimicrobial, hypoglycemic and hepatoprotective activity, which have been widely reported in the literature [10].

In Peru, the Tarma region stands out for its rich biodiversity, moderate altitude (over 3,000 m above sea level), fertile soils, and temperate climate, conditions that favor a diverse flora that potentially influences the botanical and chemical composition of collected pollen. This ecological variability, combined with altitude and temperature, contributes to generating unique profiles of bioactive compounds in local pollen, as suggested by research on the influence of geographic origin on its functional quality [11].

Drying temperature is one of the most critical factors in pollen preservation, as it directly influences the stability of its bioactive compounds. While solar drying is a common practice in artisanal beekeeping, its application without thermal control can lead to significant losses of polyphenols and antioxidant activity [12]. Therefore, recent studies have evaluated low-temperature drying techniques as a strategy to maintain the functionality of plant matrices.

The objective of this article is to evaluate the influence of different solar drying temperatures (40, 50 and 60 °C) on the polyphenol content and antioxidant capacity of bee pollen collected in Tarma, providing evidence to strengthen it.

2. Materials and Methods

2.1. Materials

2.1.1. Study Sample

The bee pollen used in this research was collected in the province of Tarma, located in the department of Junín, Peru. The pollen was collected from apiaries located at altitudes ranging from 2,900 to 3,200 meters above sea level.

2.2. Phenolic Compounds

Total phenolic compounds were quantified using the Folin-Ciocalteu reagent [13], following a colorimetric protocol. Two hundred and fifty μ L of the extract

(adequately diluted), 250 μL of 1N Folin-Ciocalteu reagent, and 625 μL of 7.5% sodium carbonate were mixed in light-protected test tubes, and the mixture was incubated for 30 minutes at room temperature in the dark. Absorbance was measured at 755 nm (UV-Vis Genesys 10S), using distilled water as a blank. For the standard curve, gallic acid solutions were prepared ranging from 0.008 to 0.072 mg/mL. The results were expressed as mg of AGE/g of sample by interpolation of the values on the calibration curve shown in Figure 1.

2.3. DPPH (2,2-diphenyl-1-picrylhydrazyl)

The antioxidant capacity of pollen was evaluated by the DPPH radical, adapting the Brand-Williams method according to Brand-Williams [14]. A working solution of DPPH (0.1 mM) was prepared by dissolving 6 mg of the reagent in 80% methanol, adjusted to an absorbance of 1.1

± 0.02 at 517 nm (UV-Vis Genesys 10S). A Trolox standard curve (100–1000 μM) was prepared by measuring the inhibition after mixing 100 μL of each standard with 1900 μL of DPPH, incubating for 30 minutes in the dark. For the samples, 100 μL of the extract was mixed with 1900 μL of DPPH under the same conditions. The absorbance was read at 517 nm. The results were expressed as $\mu\text{mol TE/g}$ of pollen by interpolation of the values in the calibration curve as shown in Figure 2.

Likewise, the results are calculated as percentage of inhibition:

$$\% \text{ Inhibition} = \left(\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right) \times 100 \quad (1)$$

Where:

A_{control} is the absorbance of the DPPH solution without sample and A_{sample} corresponds to the absorbance of the DPPH solution with the pollen extract.

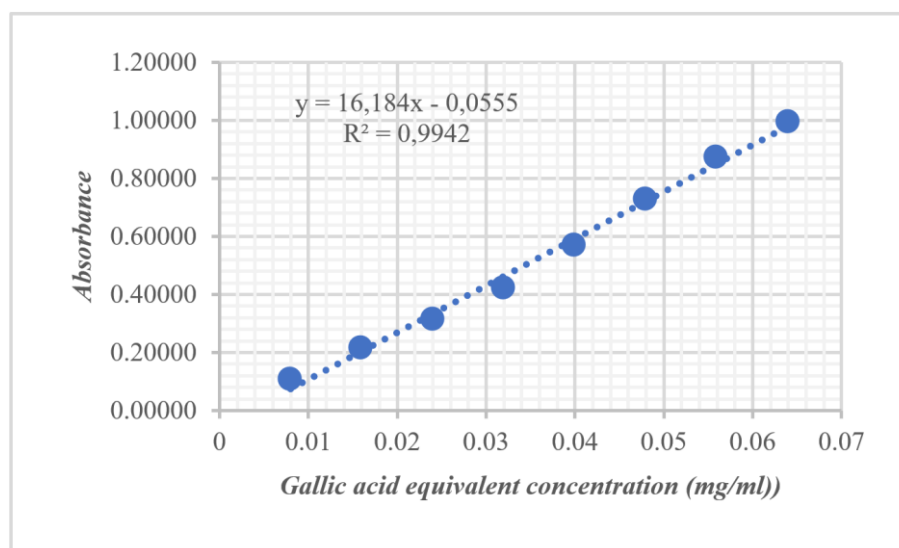


Figure 1. Gallic acid calibration curve

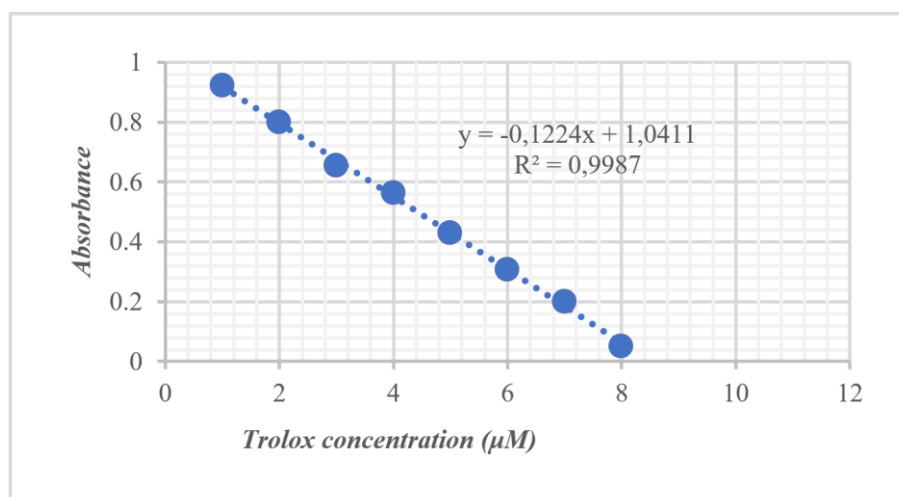


Figure 2. Trolox equivalent DPPH calibration curve

2.4. Automated Solar Dryer

Execution site: Facilities of the Faculty of Applied Sciences of the UNCP located at an altitude of 3040 m.a.s.l. and a latitude of 11°25'12" and a longitude of 75°41'17" with a solar radiation of 5.43 Kwh/m²day.

2.4.1. Technical Specifications of the Solar Collector and Drying Cabinet

The system is primarily used for the efficient drying of agricultural products, harnessing solar energy in a controlled manner. During operation, the solar collector captures and transfers heat to the air, which is directed toward the drying chamber where it circulates evenly thanks to the fans. Sensors monitor the temperature and humidity of both the air and the product in real time, and the microcontroller automatically adjusts ventilation and damper opening to maintain optimal conditions, as shown in Figure 3.



Figure 3. Weather station and automated solar drying system

Temperature and humidity control in bee pollen drying begins with system activation and continuous readings from sensors that monitor the values in the chamber. If the temperature or humidity falls outside the optimal range, the system automatically adjusts heating, ventilation, or dehumidification to maintain ideal conditions. This cycle is repeated until adequate drying is achieved, after which the process is stopped or the operator is notified. The schematic flow of this control system is illustrated in Figure 4.

Figure 5 shows solar radiation during daylight hours at the unloaded location, demonstrating the energy availability for the drying process. Figure 6 also compares ambient temperatures and those inside the unloaded drying chamber, showing a significant thermal increase inside. Finally, Figure 7 presents the temperatures recorded both in the ambient and inside the drying chamber, controlled at 55 °C, using data from the FACAP UNCP Meteorological Station. This reflects the system's efficiency in maintaining a controlled temperature to optimize the solar drying process.

The installation of a solar dryer with temperature, humidity, and weight controls improves the quality of bee pollen in accordance with technical standards. The resulting moisture guarantees its stability and, therefore, ensures a longer shelf life for the product.

The collector and drying chamber were installed with a northerly orientation, as we are in the southern hemisphere, with an inclination of 22°. Tarma is located at a latitude of approximately 12°, and we considered an inclination of 10° to take advantage of more solar radiation in winter.

Temperatures inside the drying chamber were increased during no-load testing from 7 °C with 100 W/m² to 35 °C with instantaneous radiation of 1000 W/m², achieving higher average temperatures at 12 to 14 hours on sunny days of 60 °C inside the drying chamber.

The solar drying system allows you to program the temperature inside the cabin according to the required temperature of the product to be dried in accordance with technical quality standards. It also provides the product's weight and moisture content for real-time decision-making.

2.5. Method

2.5.1. Study Design

This study was designed to evaluate the influence of different solar drying temperatures (40, 50, and 60 °C) on the polyphenol content and antioxidant capacity of bee pollen. A completely randomized experimental design was used, with analysis of variance (ANOVA) applied to determine significant differences between treatment groups. This approach allows for comparing the means of the different treatments and assessing whether drying temperatures have a significant effect on the dependent variables.

2.5.2. Experimental Procedures

The pollen samples were divided into three groups, each subjected to solar drying at temperatures of 40, 50, and 60 °C with two replicates. Drying was carried out in a controlled solar dryer, where temperatures were monitored to ensure they remained constant throughout the process. Once drying was complete, data were collected using the following analytical methods:

1. Determination of Total Polyphenols: The Folin-Ciocalteu method was used, which allows measuring the total polyphenol content in the samples. This method is widely recognized for its ability to correlate polyphenol content with antioxidant activity [15].

2. Antioxidant Capacity Assessment: Antioxidant activity assays, including the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, were applied to evaluate the ability of pollen extracts to neutralize free radicals as explained above in the "Materials" section. This method is effective in determining the antioxidant potential of compounds present in pollen [16].

2.5.3. Statistical Analysis

The data obtained from the polyphenol and antioxidant capacity assays were analyzed using a one-way analysis of variance (ANOVA) to determine whether there were significant differences between the drying treatments. A

significance level of $p < 0.05$ was used for all statistical tests. When significant differences were detected, post hoc tests using Tukey's comparison of means were performed to identify which treatments showed significant differences. Statistical analysis was performed using IBM SPSS Statistics version 25.

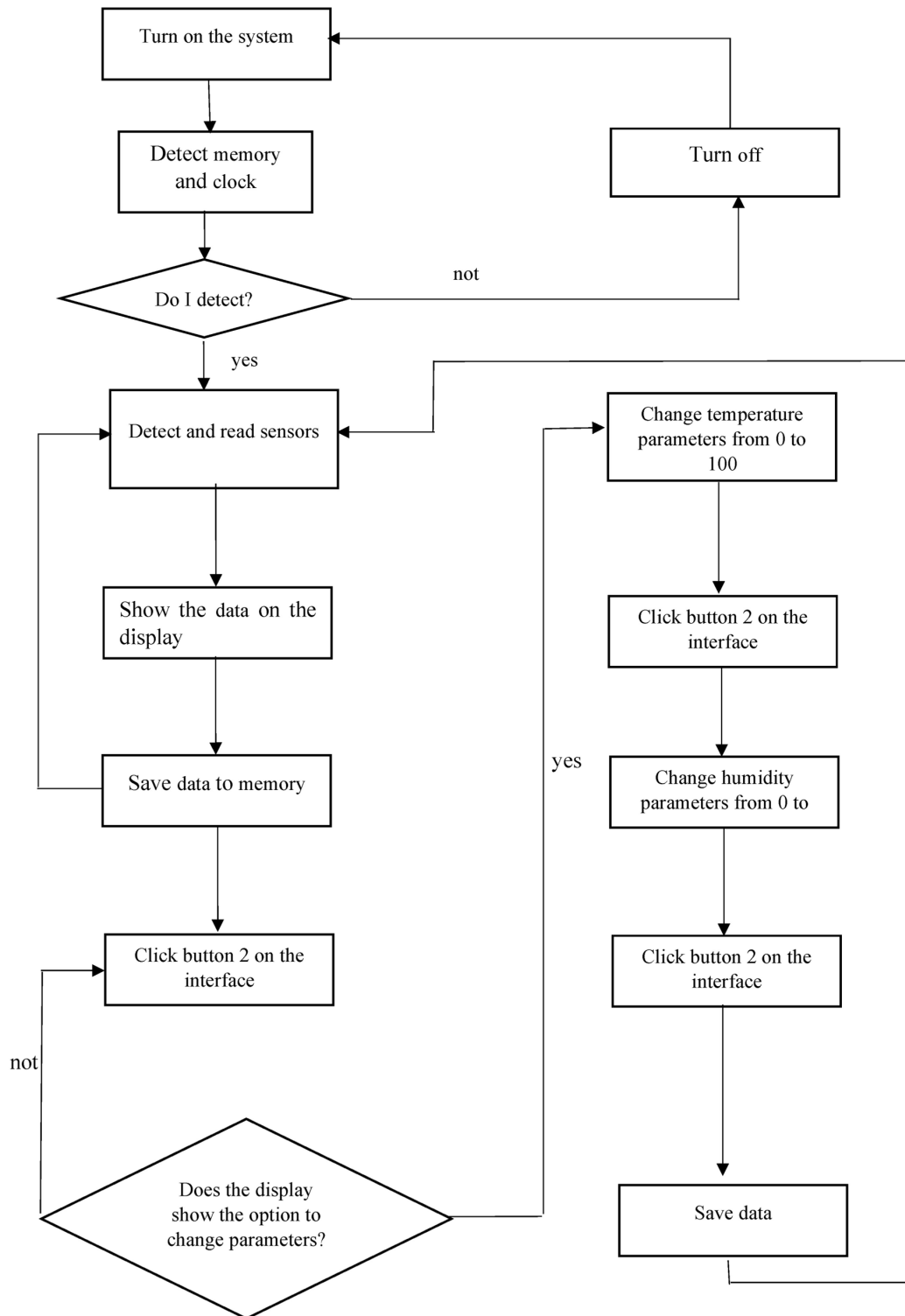


Figure 4. Temperature and humidity control flow chart

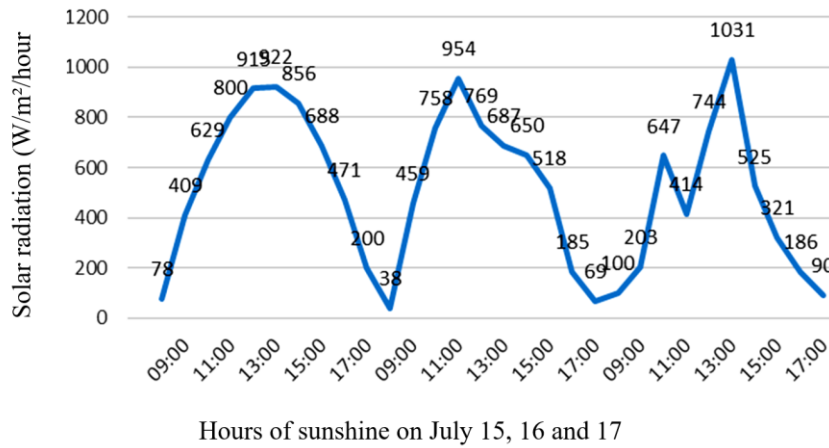


Figure 5. Solar radiation during hours of sunshine at the location where the solar dryer is installed without charging

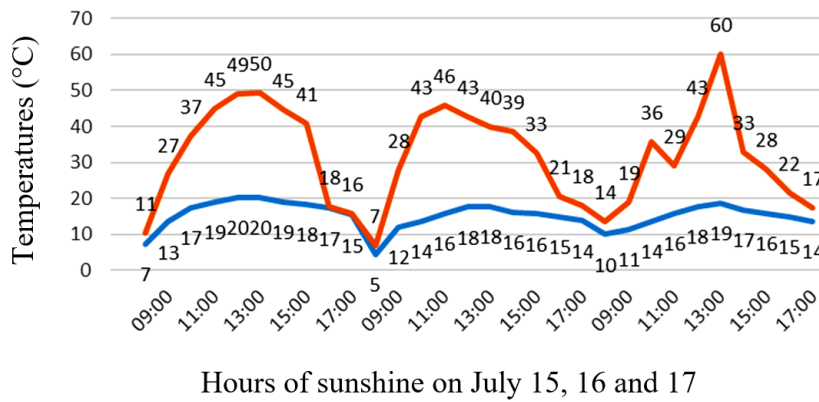


Figure 6. The lower curve is for ambient temperatures and the upper curve is for the drying chamber without load

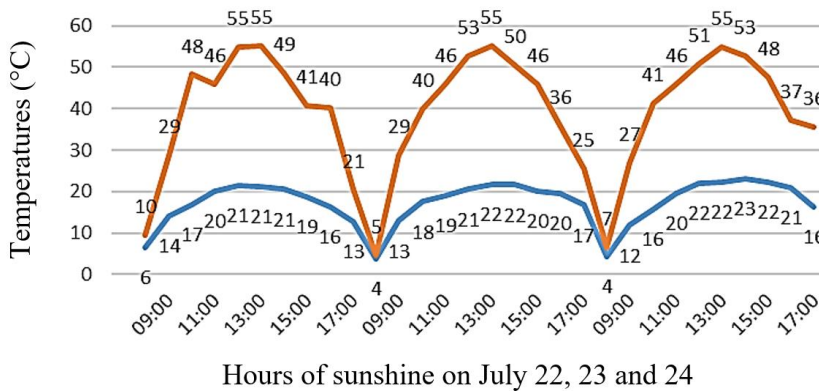


Figure 7. Curve of recorded ambient temperatures and, at the top, temperatures inside the drying chamber (Taken from the FACAP UNCP Meteorological Station and database of the solar dryer with control at 55 °C)

It is important to note that the functional quality of pollen was determined solely through the measurement of total polyphenols and antioxidant capacity. This implies that other bioactive compounds present in pollen, which could contribute to its functional properties, were not considered

in this study. This limitation suggests that future studies could benefit from a more comprehensive approach that includes the evaluation of other bioactive compounds and their interactions.

3. Results

3.1. Pollen Humidity before and after Drying

Table 1 shows the moisture content of fresh pollen and pollen subjected to solar drying at 40, 50, and 60 °C. Fresh pollen had a value of $17.896 \pm 0.11\%$, which decreased significantly to $12.066 \pm 0.12\%$, $11.886 \pm 0.08\%$, and $10.721 \pm 0.06\%$ with increasing temperature. Statistical differences were observed between treatments ($p < 0.05$), indicating that higher temperatures resulted in greater efficiency in moisture reduction. The low standard deviations reflect consistency and reliability in the measurements taken.

Table 1. Moisture content of fresh pollen and dehydrated pollen at different temperatures

Treatment	% Humidity	
	$\bar{x} \pm DE$	
Fresh pollen	17,896a	0,11
Dried at 40 °C	12.066b	0.12
Dried at 50 °C	11.886c	0.08
Dried at 60 °C	10.721	0.06

3.2. Total Phenols and Antioxidant Capacity

The phenolic compound content and antioxidant

capacity were determined in fresh pollen (raw material) and in dehydrated pollen at temperatures of 40 °C, 50 °C, and 60 °C with two replicates. The results obtained are presented in Table 2.

The results indicate that drying temperature has a significant impact on both the phenolic compound content and the antioxidant capacity of pollen. As temperature increases, the concentration of phenolic compounds increases, reaching a maximum value of 1.090 mg EAG/g of sample at 60 °C, while the lowest concentration is detected at 40 °C (0.870 mg EAG/g of sample).

On the other hand, the antioxidant capacity of pollen is also positively influenced by increasing drying temperature. The highest inhibition value is observed at 60 °C (45.36%), while the lowest antioxidant capacity is observed at 40 °C (37.39%).

To establish the significant difference between temperatures, an analysis of variance (ANOVA) was performed with a 95% confidence level. Figures 8 and 9 show the Tukey means comparison test for phenolic compound content and antioxidant capacity, respectively. Figure 8 shows that, for phenolic compounds, there are significant differences ($p < 0.05$) between samples dehydrated at 40 °C, 50 °C, and 60 °C.

The highest phenol content was found at 60 °C, followed by samples treated at 50 °C and 40 °C, respectively. Different letters above the bars indicate statistical differences between the means.

Table 2. Average content of phenolic compounds and antioxidant capacity in pollen by effect of drying temperature

Drying temperature °C	N	Phenolic compounds		Antioxidant capacity			
		mg EAG/g sample		% Inhibition		μmolTE/g sample	
		$\bar{x} \pm DE$		$\bar{x} \pm DE$		$\bar{x} \pm DE$	
40 °C	2	0,870 ^c	0.002	37,390 ^c	0.905	0.112 ^c	0.003
50 °C	2	0,960 ^b	0.088	41,910 ^b	1.387	0.126 ^b	0.004
60 °C	2	1,090 ^a	0.122	45,360 ^a	1.594	0.136 ^a	0.005

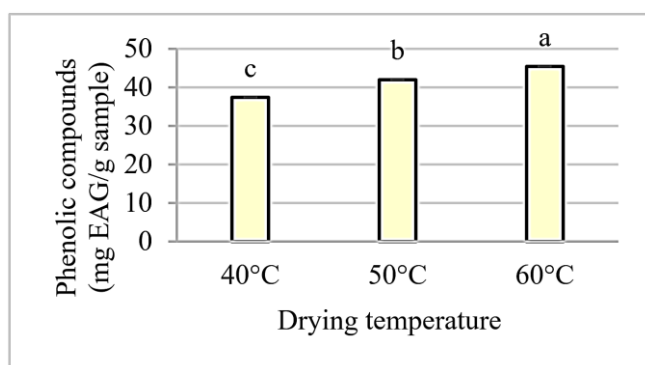


Figure 8. Comparison of Tukey means for phenolic compound content by drying temperature

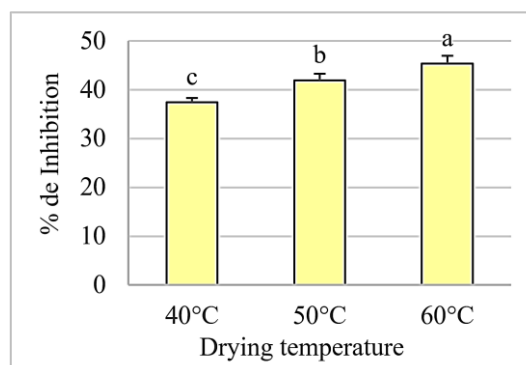


Figure 9. Comparison of Tukey means for antioxidant capacity by effect of drying temperature

Similarly, Figure 9 illustrates the comparison of the average antioxidant capacity, which also shows significant differences between the three treatments. The highest antioxidant capacity is reached at 60 °C, significantly higher than that obtained at 50 °C and 40 °C. The 50 °C treatment has an intermediate value, while the 40 °C treatment has the lowest antioxidant capacity.

4. Discussions

According to the article by Moscoso et al. [1], polyphenols are bioactive compounds found in various plants and foods, known for their antioxidant properties. In the context of aging and chronic non-communicable diseases, polyphenols can help mitigate oxidative stress and, therefore, reduce the risk of these diseases with our research we agree with what was mentioned according to polyphenols.

The article by Castellanos-Paez et al. [2] investigates the effects of solar drying on the structural and thermodynamic characteristics of bee pollen. The study compares solar drying with the conventional dehydration process in booths, highlighting operating conditions such as an average temperature of 19-35 °C and a relative humidity of 55%. Significant changes in pollen structure are observed. Our results are similar regarding the use of solar dryers in preserving pollen properties.

El-Mesery et al. [3] review the latest advances in solar drying technology applicable to food and agricultural products. The study examines innovative techniques that improve the efficiency and sustainability of solar drying. Our study asserts that the solar dryer is a device that preserves the organoleptic properties of pollen.

The study by Shuyao et al. [4] investigates how different drying methods affect the color, phenolic acid content and antioxidant activity of bee pollen. In our study we agree with the above, since if there is no control of temperature and humidity, the organoleptic characteristics of the pollen are affected.

The amount of polyphenols increases in dehydrated pollen samples when the temperatures corresponding to 40, 50 and 60 °C increase, where the polyphenol content increases as is according to their means and 95% confidence intervals, as shown in Table 1. This difference is significant by ($P < 0.05$). Our results are similar to those obtained by Zuluaga et al. [5] who obtained very close polyphenol contents between pollen samples dried at 40, 50 and 60 °C.

In our study, the functional quality analysis of fresh pollen and dehydrated pollen was carried out at three different temperatures: 40, 50 and 60 °C. In the case of the functional quality analysis, antioxidant capacities were considered (Table 1), where it is evident that higher temperatures improve the antioxidant capacity.

In the case of total polyphenols, there is also a significant increase in drying of dehydrated pollen from 40 to 60 °C

(Figure 8); this is similar to that developed by Zuluaga et al. [5], who also analyzed dehydrated pollen at the same temperatures, but their analysis of bioactive compounds included the content of phenolic compounds, carotenoids, flavonoids and antioxidant capacity. The results on the antioxidant capacity of dehydrated pollen show direct differences, the higher the drying temperature, the greater the antioxidant capacity as shown in Figure 2; thus we have that the sample dried at 40 °C presents .80367 mM, at 50 °C it presents 80722 mM and at 60 °C it presents 86400 mM. This coincides with that obtained by Zuluaga et al. [5], which states that with the increase in temperature the antioxidant capacity increases slightly.

On the other hand, it is also indicated that moisture content represents a crucial parameter in the preservation of bee pollen, since levels above 14% can promote the growth of microorganisms and accelerate oxidation processes. In this sense, our finding of an initial moisture content of $17.896 \pm 0.11\%$ in fresh pollen, which was reduced to $12.066 \pm 0.12\%$ at 40 °C, and to $11.886 \pm 0.08\%$ and $10.721 \pm 0.06\%$ at 50 °C and 60 °C respectively, highlights the effectiveness of solar drying according to Keskin [6] who reported that drying at higher temperatures tends to reduce moisture content more effectively, which, in turn, could improve the stability of bioactive compounds present in pollen. Although the humidity levels achieved do not meet the recommended technical standard for dry pollen (<8%), they are indicative of the potential of solar drying as a viable pre-preservation strategy.

According to Kim et al. [7], optimizing variables such as drying duration and the incorporation of forced air flow could help achieve desirable moisture levels, while improving the functional quality of the product. Moreover, recent research has shown that the antioxidant capacity of polyphenols in pollen is directly affected by its moisture content and drying conditions, which underlines the importance of appropriate preservation methods to preserve antioxidant activity.

Pollen drying at 40, 50 and 60 °C was also chosen to effectively reduce its moisture content without affecting its nutritional and functional properties. The Artisan Technical Standard [8] recommends 40 °C as a safe temperature for preserving heat-sensitive compounds. However, recent research by Kaur et al. [9], El Ghouizi et al. [11] has shown that slightly higher temperatures, such as 50 and 60 °C, not only speed up the drying process but also maintain the quality of the pollen, ensuring its stability and functionality as a food.

According to Peruvian and international regulations related to food processing, especially for bee pollen, it is recommended that drying processes not exceed 45 °C, as higher temperatures can negatively affect certain heat-sensitive bioactive compounds, such as vitamins and antioxidants. However, our research findings show an interesting exception: when drying at a temperature of 60 °C, a significant increase in total polyphenol levels was observed. These compounds, recognized for their health

benefits due to their antioxidant properties, not only remained stable but also increased. Furthermore, antioxidant capacity, which measures the ability to neutralize free radicals and prevent oxidative damage, also showed a notable increase under these drying conditions. These results suggest that, in certain cases, higher temperatures can enhance the concentration and activity of bioactive compounds, likely due to the release of previously bound polyphenols or structural changes in the food matrix that facilitate their availability.

5. Conclusions

The results of this research reveal that solar drying temperature influences the antioxidant capacity of bee pollen, showing that higher temperatures present an increase in the concentration of these bioactive compounds, as shown in Figure 8. It is also important to highlight that the difference in polyphenol content between drying treatments at 40, 50, and 60 °C was statistically significant at higher temperatures. This suggests that, although temperature has a positive effect, this may not be marked enough to be considered relevant in the range studied. Furthermore, the functional quality of pollen was determined solely through the measurement of total polyphenols and antioxidant capacity, which limits a full understanding of its nutritional properties.

In response to the objective of this research, which was to evaluate the influence of different solar drying temperatures (40, 50, and 60 °C) on the polyphenol content and antioxidant capacity of bee pollen, as shown in Figure 9, it is concluded that solar drying may be a viable technique for pollen preservation, although appropriate temperatures should be considered to maximize the retention of bioactive compounds. This study is part of an original research article, using an ANOVA methodological design, which allowed for an effective analysis of differences in results.

6. Recommendations

It is recommended that future studies address a more comprehensive analysis of other bioactive compounds present in pollen, as well as a comparative evaluation of different drying methods and their impact on pollen quality and stability over time. These studies could significantly contribute to the updating and optimization of national and international technical standards related to pollen drying, especially under higher temperature conditions.

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REFERENCES

- [1] Moscoso M., Bonilla A., Rivera D., Veloz M., "Oxidative stress in aging and chronic non-communicable diseases," *Scientific Information Journal*, vol. 103, 2024. <https://doi.org/10.5281/zenodo.13829804>
- [2] Castellanos B., Durán, A., Fuenmayor C., Quicazán M., Zuluaga C. M., "Effects of solar drying on the structural and thermodynamic characteristics of bee pollen," *Vitae*, vol. 29, no. 3, pp. 1-12, 2022. <https://doi.org/10.17533/udea.vitae.v29n3a350572>
- [3] El-Mesery H., El-Seesy A., Hu, Z., Li Y., "Recent developments in solar drying technology of food and agricultural products: A review," *Renewable and Sustainable Energy Reviews*, vol. 157, 2022. <https://doi.org/10.1016/j.rser.2021.112070>
- [4] Shuyao W., Yanxiang B., Zidan Z., Wenjun P., Wenli T., Hui W., Xiaoming F., "Effects of pulsed vacuum drying temperature on drying kinetics, physicochemical properties and microstructure of bee pollen," *Food Science and Technology*, vol. 169, 2022. <https://doi.org/10.1016/j.lwt.2022.113966>
- [5] Zuluaga C., Serrato J., Quicazan M., "Influence of drying-related operations on microbiological, structural and physicochemical aspects for bee pollen," *Engineering in Agriculture Environment and Food*, vol. 11, no. 2, pp. 57-64, 2018. <https://doi.org/10.1016/j.eaef.2018.01.003>
- [6] Keskin S., Özkök A., "The effects of drying methods on the chemical composition and volatile compounds of bee pollen," *Journal of Food Science and Technology*, vol. 57, no. 9, pp. 3358-3368, 2020. <https://doi.org/10.1007/s11483-020-02262-x>
- [7] Kim S., Jo Y., Liu Q., Ahn J., Hong I., Han S., Lee M., "Optimization of extraction condition of bee pollen using response surface methodology, correlation between antimelanogenesis, antioxidant activity, and phenolic content," *Molecules*, vol. 20, no. 11, pp. 19764-19774, 2015. <https://doi.org/10.3390/molecules201119656>
- [8] Artisanal Technical Standard for Honey and Bee Products. "Honey and bee products (Version 2). Government of Navarra", 2023. Retrieved from https://www.navarra.es/NR/rdonlyres/626019EE-6BBC-4CF7-94A0-1C955CE336DC/0/051NTAMielyproductosapicolos_V0_.pdf
- [9] Kaur J., Rasane P., Kumar V., Nanda V., Bhadariya V., Kaur S., Singh, J. "Exploring the health benefits of bee pollen and its viability as a functional food ingredient," *Reviews in Agricultural Science*, vol. 12, pp. 65-78, 2024. https://doi.org/10.7831/ras.12.0_65
- [10] Alshallash S., Abolaban G., Elhamamsy M., Zaghlool A., Nasr A., Nagib A., El-Hakim F., Zahra A., Hamdy E., Taha M., "Bee pollen as a functional product – Chemical constituents and nutritional properties," *Journal of Ecological Engineering*, vol. 24, no. 2, pp. 173-183, 2023. <https://doi.org/10.12911/22998993/156611>
- [11] El Ghouzi A., Bakour M., Laaroussi H., Ousaaid D., El

- Menyiy N., Hano C., Lyoussi B., "Bee pollen as functional food: Insights into its composition and therapeutic properties," *Antioxidants*, vol. 12, no. 3, pp. 557, 2023. <https://doi.org/10.3390/antiox12030557>
- [12] Campos R., Frigerio C., Lopes J., Bogdanov S., "What is the future of bee-pollen?," *Journal of ApiProduct and ApiMedical Science*, vol. 1, no. 1, pp. 38–49, 2021.
- [13] Singleton L., Rossi A., "Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents," *American Journal of Enology and Viticulture*, vol. 16, no. 3, pp. 144-158, 1965. <https://doi.org/10.5344/ajev.1965.16.3.144>
- [14] Brand-Williams W., Cuvelier M., Berset C. "Use of a Free Radical Method to Evaluate Antioxidant Activity" *LWT-Food Science and Technology* , vol. 28, pp. 25-30, 1995. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)
- [15] Hossain M., Lebel J., Birsan R., Dilip K., "Enrichment and assessment of the contributions of the major polyphenols to the total antioxidant activity of onion extracts: a fractionation by flash chromatography approach," *Antioxidants*, vol. 7, no. 12, pp. 175, 2018. <https://doi.org/10.3390/antiox7120175>
- [16] Mohdaly A., Mahmoud A., Roby M., Smetanska I., Ramadan M., "Phenolic extract from propolis and bee pollen: composition, antioxidant and antibacterial activities," *Journal of Food Biochemistry*, vol. 39, no. 5, pp. 538-547, 2015. <https://doi.org/10.1111/jfbc.12160>