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Closed flow solar dehydration with the use of silver nanoparticles: Application for the production of *Pouteria lucuma* flour

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ABSTRACT

In this research, a closed-flow solar dehydrator with a refrigeration moisture extraction system was evaluated, likewise, the dehydration temperature time was optimized by evaluating three types of heat transfer fluids. The dehydration equipment included devices to absorb thermal energy from incident sunlight, such as a trombe wall and a parabolic cylindrical collector, and a thermo bank system. In addition, the influence of three types of heat transfer fluids (water, oil and oil nanofluid + silver nanoparticles) was evaluated. This dehydration system was applied to process the *Pouteria lucuma* fruit. The results indicate the reduction of the dehydration time by 58.19% using nanofluid. This treatment prevents the modification of the physicochemical properties of the product and helps preserving its organoleptic properties.

KEYWORDS

Solar dryer; heat transfer fluid; nanofluid; *Pouteria lucuma*; refrigeration

1. Introduction

Dehydration is considered a very important process, because it allows us to preserve and therefore extend the useful life of food,[1–3] this as a result of the reduction of the levels of water content in organic products. At an economic and productive level, it allows access to more distant markets.[4,5] Another advantage of dehydration is that it allows to have fruits in seasons where they are not normally produced, thus achieving better prices. It also has a microbiological aspect, since the water contained in food induces the proliferation of microorganisms[6–9] or favors biochemical reactions that spoil these foods.[10] Hence, dehydration can help reducing the risk of fruit spoilage.

At present there are various drying and dehydration systems using conventional energies[11–15] and unconventional,[16–19] in addition to processes based on ultrasound drying, natural convection, forced convection, vacuum and freezing (lyophilization). The processing phase is important, because it generates changes in the sensory and nutritional properties of the food; one of the commonly practiced methodologies is to leave the product exposed to the sun for several days for prolonged drying, however, high temperatures and direct exposure to the sun cause the product to shrink and alter its organoleptic properties.[20–23] There are systems that use fossil fuels as an energy source, which contributes to the emission of greenhouse gases, in addition to increasing the carbon footprint.[24]

Closed flow dehydration increases the drying speed, generates a faster increase in the temperature of the dehydration chamber, and also prevents the aroma of the fruit from being lost.[25–29] A process that allows to minimize the losses of its organoleptic properties is lyophilization, reducing undesirable changes, resulting in high quality products, but with high sales costs.[30–32]

Solar thermal systems consist of a receiver or collector, thermal energy storage and power pack, if required.[33–36] Recent research in the field reveals that different types of nanofluids[37] can increase the working temperature of the heat transfer fluid and improve the thermal conductivity and heat transfer properties of the fluid.[38]

The closed flow systems have the problem of how to extract moisture; given this it is necessary to use the technological contribution of a refrigeration system, it should be mentioned that the literature is scarce where they consider a reverse sublimation system and refrigeration fusion, however, this research provides information about it.

Motivation for the use of non-conventional (renewable) energies has been increasing in recent years,[39–42] likewise, has been reflected in the increase in research studies where science and engineering have been generating various designs for systems that allow their use and transformation.[43–48] Solar energy is an unlimited, nonpolluting and cheap source of energy, the use of which significantly reduces operating costs, in addition to contributing to the mitigation of climate change and the reduction of the carbon footprint.[24]

At present the international market has a tendency to consume ecological and healthy products, dehydrated foods being an excellent option; in this sense, enormous efforts have been made to achieve new ecological and sustainable technologies based on innovative processing techniques, with the energy aspect and product quality being key objectives in production.[49]

On this occasion we are going to apply the operation of the proposed equipment in the dehydration of the lucuma fruit (*Pouteria lucuma*), an fruit that has excellent nutritional properties.[50–52] Its international demand has been growing in the last decade.[4] However, the shelf-life of this fruit is very sensitive to ripening, which complicates its transfer to foreign markets. This is how currently countries in Asia, Europe and the United States request this product in greater quantity but as frozen, and in some cases in dehydrated form, considerably increasing their price since they use complex techniques such as lyophilization. Solar dehydration, using innovative techniques that allow obtaining a quality product, would be an excellent contribution to this area, and for applications in other types of fruits.

Therefore, this research aimed to develop a closed-flow solar dehydration system coupled to a refrigeration-assisted inverse sublimation and moisture removal process. Likewise, the corresponding improvement was evaluated with regard to the optimization of the time required for achieving the ideal dehydration temperature through the application of high efficiency heat transfer fluid by forced convection. For this purpose, the effects of the use of three types of fluids such as: water, oil and nanofluid (oil + silver nanoparticles) were investigated. It is worth mentioning that the silver nanoparticles used for this purpose were synthesized by a sustainable method.

As a result of this study, the most suitable fluid was to be chosen for the dehydration of the *Pouteria lucuma* fruits.

2. Materials and methods

2.1. Preparation of samples

For the practice of the dehydration process, the lucuma fruit (*Pouteria lucuma*) was used, which was acquired from a single source being a field located in the district of Moche, province of Trujillo, in Peru. The product was purchased two days prior to each experimental run and was stored under refrigeration at 9 °C until used. One day prior to the test, the product was removed from the refrigerator and placed at room temperature (23 °C).[53] It is worth mentioning that the selection of the fruit was due to its degree of maturity, similar size and without visual defect. As an initial evaluation a physical-chemical analysis of the fruit was carried out. The fruit, once selected, was washed and disinfected with chlorine dioxide solution at 40 ppm by immersion for 3 minutes, then it was manually peeled, after which the seeds were removed with the aim of having the pulp only. Finally, 0.3 mm. thick slices with diameters of 3.0 cm. were made.

2.2. Uncertainty analysis

Uncertainty analysis refers to the uncertainty or error in experimental data. A systematic error in the experimental data is a repeated error of constant value and the random error is due to an imprecision. The systematic error can be removed by a calibration but the random error cannot be removed. The imprecision due to the random error can be defined numerically by a calibration. The measured data on solar radiation, temperature and relative humidity were recorded during the calibration. The mean value of the measurements and standard deviation of the random errors of the data on solar radiation, temperature and relative humidity were determined. The variable x_i which has an uncertainty dx_i is expressed as[54–56]:

$$x_i = x_{mean}(measures)\ 6\ dx_i$$

where x_i is actual value of the variable, x_{mean} is mean value of the measurements; and dx_i is the uncertainty in the measurement. There is an uncertainty in x_i that may be as large as dx_i. The value of dx_i is the precision index which is taken as two times the standard deviation and it encloses approximately 95% of the population for a single sample analysis.[57]

Measurements of temperature, humidity and mass in this study were conducted with uncertainties such as temperature (°C) in ± 0.1 °C, humidity (%) in ± 0.1%, and mass (g) ± 1 mg.

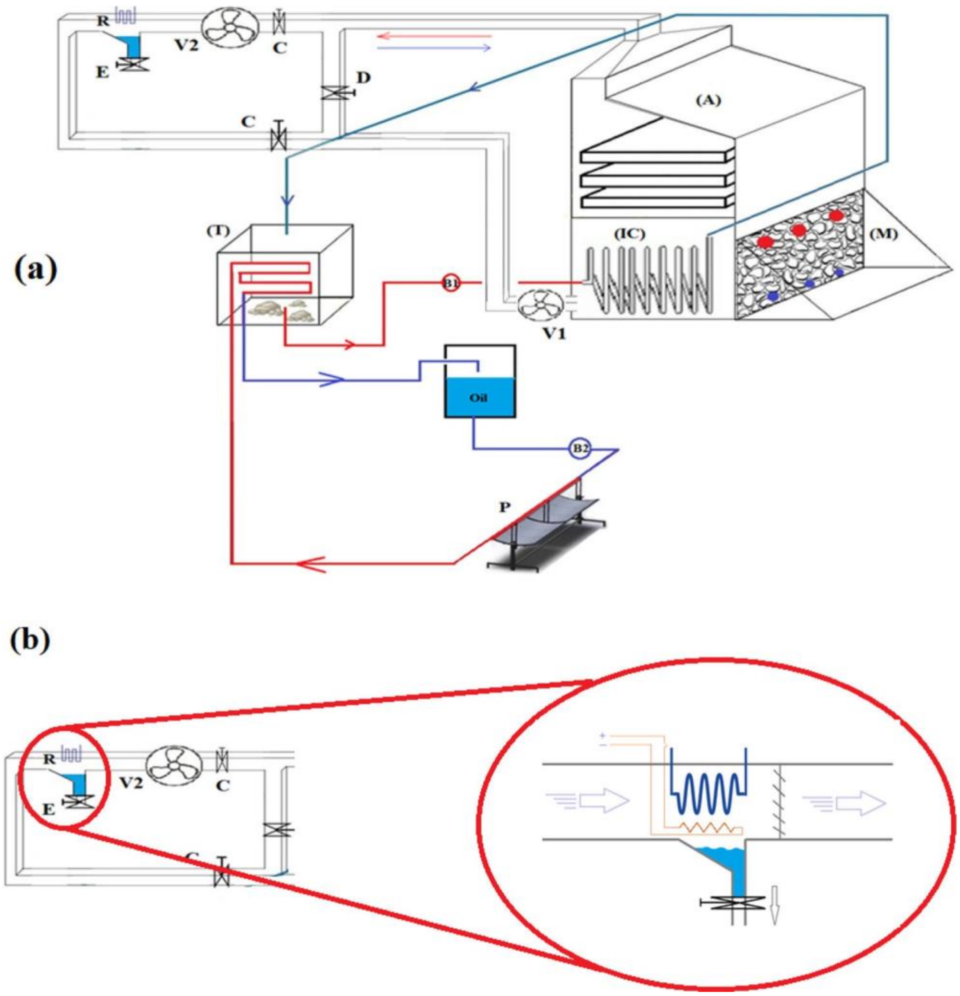

Figure 1. (a) Isometric view of the solar dehydrator equipment. (b) Details of refrigeration system for moisture extraction.

2.3. *Experimental procedures*

The experimental activity was carried out in the city of Trujillo, La Libertad region in Peru, for which measurements such as solar radiation were considered, which was measured with a pyranometer (model MP-200 ICT international, precision 0.5%), this sensor was located in the upper external part of the dehydration chamber. A climatological recorder (temperature and humidity) with data logger (model PCE-HT 71 N) was used to measure the air parameters in the equipment. A hot wire anemometer (Lutron, model AM-4204, accuracy 2%) was also used to control the air velocities inside the closed flow system.

2.4. *Design and construction of an innovative closed-flow solar dehydrator*

In this research, two sources of heat energy have been coupled, Trombe Wall and Cylindrical Parabolic Collector. Figure 1(a) shows isometric view of the innovative solar dehydration equipment, the design consists of two sources of heat energy such as a parabolic cylindrical collector (P), where the receiver focus of the horizontal parabola has a glass tube external to the copper pipe. Its purpose is to improve the heating process of the fluid (water). It will collect the heat due to the incidence of the solar rays in the geometric focus, and will be transported through metal pipe (copper) to the thermo bank (T) where a second heat transfer fluid will be housed.

The solar dehydrator in question, in its operating phase, does so by means of a closed cycle by forced convection, thus preventing that some volatile compounds of the fruit that give it flavor and aroma from being lost. However, since it is necessary to remove the moisture from the dehydrator, a refrigeration system was added which initially froze the moisture, and then (using an electric heater) converted it to a liquid state to later remove it to the outside (See Figure 1(b)).

The design also considers the storage of heat. For this purpose, a "thermo bank" has been added. The

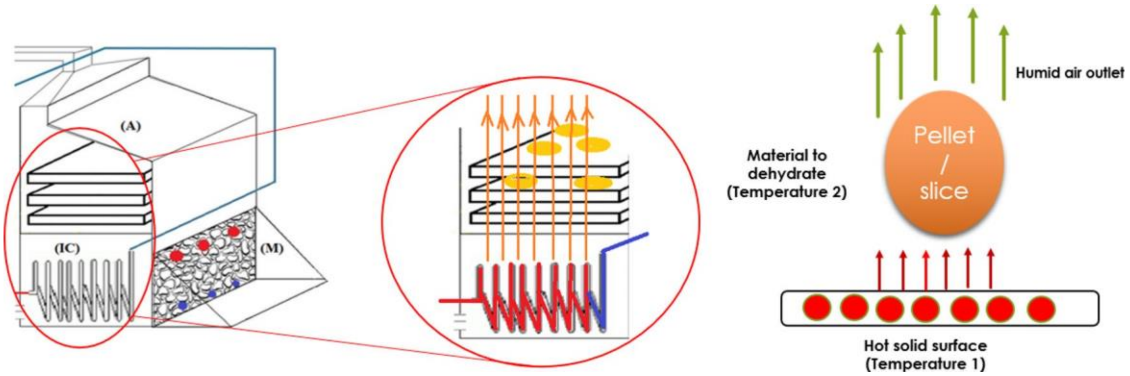

Figure 2. Heat transfer process through the heat exchanger to the trays containing the lucuma slices to be dehydrated.

latter contains stones that act as thermal batteries and balance the heat contributed by the aforementioned sources.

There are various types of equipment for drying/ dehydrating food, however, not many of them consider improving thermal efficiency and avoiding the loss of organoleptic properties of the product.

The fluid in question will be directed through copper tubing to the lower part of the dehydration chamber, where a heat exchanger (IC) will be located, which will begin to emit heat by radiation (by natural convection), see Figure 2, this process occurs by forced convection of heat transfer fluid using an electric pump. It should be noted that in the upper part of the dehydration chamber (A), there are the trays that contain the slices of the lucuma fruit.

Another heat source is the Trombe Wall (M). It consists of closed glasses that surround the external part of the wall. The glass has the function of generating a greenhouse effect in that area, and by natural convection it provides heat to the chamber (A), the operating mechanism of the Trombe Wall is that when the heated air will enter through the upper openings (due to the difference in density of the hot air) and will interact with the samples (fruit slices), see Figure 3, and once this air will reenter through the lower openings of the wall for heating by greenhouse effect, this cycle will be repetitive; in addition, the wall is made of concrete and stones, which act as a heat accumulator.

The dehydration process is by forced draft, using a fan with a wind speed of 3 m/s, where the hot air will have a dynamic behavior and a closed flow, until reaching a temperature of 50 °C in the dehydration chamber, which is allowed for dehydrating lucuma, since higher temperatures have a negative effect on the cellular structure of the fruit.[58–60]

Once the temperature was reached, the second refrigeration cycle was opened, which will transport the humidity of the enclosure from the dehydration chamber to the refrigeration chamber. Through the process of reverse sublimation, the humidity will be frozen and become ice. Through a subsequent fusion process, the ice will be converted into a liquid and then removed to the outside (E).

2.5. Influence of the type of heat transfer fluids

Currently, the heat transfer fluids commonly used in flat solar collectors are known to have low thermal conductivity.[61] However, adding nanoparticles to base fluids shows an improvement in the absorption capacity of visible light[62] and in its thermal conductivity. These are results using gold and copper nanoparticles.[63] This research work is committed to using a silver-based nanoparticles (NP Ag) synthesized by a sustainable method.[64]

In this research, the influence of three types of heat transfer fluids was evaluated: water, oil and nanofluid (oil + NP Ag). As a preliminary activity to evaluate the kinetics of the temperature increase, tests were carried out at the laboratory level, where the aforementioned fluids were tested in thermally insulated Petri dishes (30 mL), under the influence of direct solar radiation for 30 minutes. During this period, all the samples were simultaneously evaluated by measuring their temperature. The heat transfer fluid samples were tested with three replications. The results are presented as averages. The nanofluid was prepared at a ratio of 2:1 (oil: NP Ag) at room temperature. It was subjected to magnetic stirring at 600 rpm for 30 minutes.

Subsequently, each heat transfer fluid was evaluated individually for 60 minutes in the solar dehydrator, where a net volume of 20 L was added in the thermo bank. This enabled us to study the heat transfer process from the exchanger (IC) to the air in the dehydration chamber.

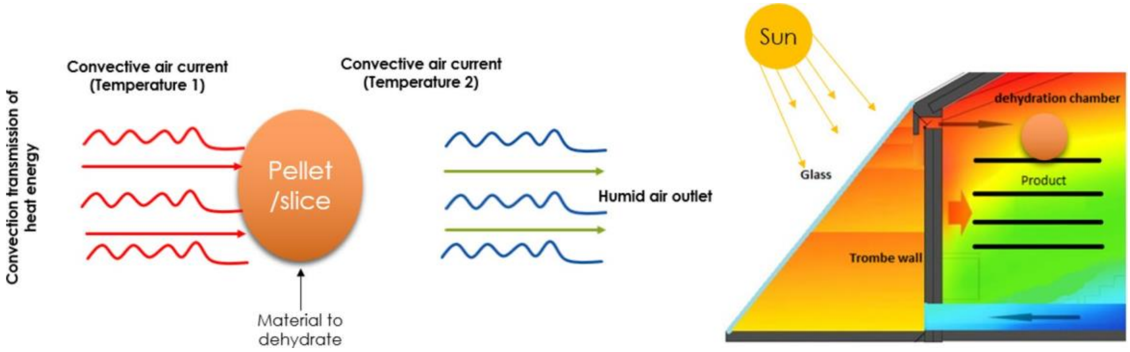

Figure 3. Heat transfer process provided by the Trombe Wall.

2.6. Quality evaluation of the dehydrated lucuma

2.6.1. Organoleptic properties

The organoleptic characteristics of the dehydrated lucuma are an important factor in determining the quality and acceptability of the product. A sensory evaluation was carried out by 15 duly trained panelists. Three characteristics were evaluated: flavor, aroma and color. The samples evaluated were lucuma powder.

For this purpose, the hedonic scale was used where the panelist had five options to choose from, the panelists were given a total of 15 grams of powdered lucuma (3 grams per sample), for which the samples were previously coded, and were finally distributed at random.

The results were evaluated using the Friedman test, considered a non-parametric test, and is equivalent to the ANOVA test. The test in question is used in situations in which "n" groups of "k" elements are selected so that the elements of each group are the most similar to each other. Based on the results, the null hypothesis is usually rejected when the value of “T” is greater than the value of the Chi-square distribution table, all with a significance level of a.

The null hypothesis that differs is when the responses associated with each of the treatments have the same probability distribution, compared to the alternative hypothesis that at least the distribution of one of the responses differs from the others.

2.6.2. Analysis of physical and chemical properties

The effects of different treatments were evaluated on the basis of following properties: Humidity according to AOAC method No. 981.05,[65] Protein for Kjeldahl method,[66] Fat for Soxlhet method, according to AOAC method,[67] Carbohydrate for indirect method,[68] Ash (carried out by incineration in muffle according to AAOC method) and soluble solids (°Brix) using ABBE refractometer (Zeiss brand).

3. Results and discussion

3.1. Evaluation of the influence of the heat transfer fluids

The temperature changes of the heat transfer fluids recorded at the laboratory level are presented in Figure 4. Figure 4 (a) shows that the nanofluid (oil + NP Ag) is the one with the best temperature gradient on average (2.55 °C/min.). The oil fluid has a gradient of 2.2 °C/min, and finally the one with the lowest value is water (1.62 °C/min).

Figure 4 (b) shows the variation of the temperature of each of the fluids under study.

Based on the results presented in Figure 4, the specific heats of each heat transfer fluid were calculated, these results are detailed in Table 1.

These results indicate that oil is the heat transfer fluid that it would need less heat supplied to the system for its temperature gradient to increase by 1 °C. Equation (1) shows the relationship of proportionality between density and specific heat (Cp), both values being inversely proportional, and therefore this would lead to the conclusion that, by increasing the density (q), the specific heat (Cp) would have to decrease, this behavior can be observed when evaluating the aforementioned fluids. In the equation we also find values for volume (V), temperature (T °), and heat (Q).

$$C_p = \frac{Q}{qVDT^{\circ}} \qquad (1)$$

The results obtained from experiments would imply the advantage of using oil as heat transfer fluid because it has the lowest specific heat value (Cp). However, the results presented in Figure 4 show an advantage of using the nanofluid. To explain this fact, it is important to mention that specific heat is not related with ‘thermal conductivity’, since this physical property is related to the behavior of the electrons. In contrast, the specific heat (Cp) is based on the

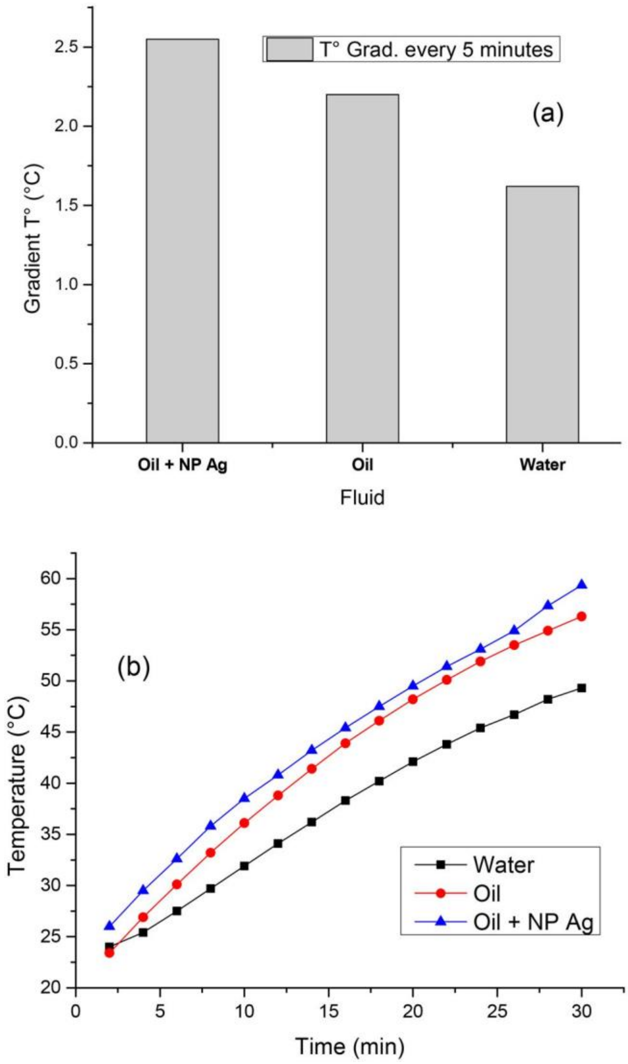

Figure 4. Temperature changes of the heat transfer fluids. (a) Average temperature gradient ratio for each heat transfer fluid. (b) Increase in temperature for each heat transfer fluid.

vibration of the phonons, which is explained by the Debye Model. This model explains a higher increase in temperature observed when silver nanoparticles are added to the oil leading to an increase in its thermal conductivity and the so-called nanofluid is obtained.[69]

The theory of molecular thermodynamics explains the reasons for temperature gradient of the nanofluid this because the nanomaterial has a high thermal conductivity. Combining the nanomaterial with the oil generates an increase in its effective thermal conductivity.[70] Another point to consider is that, by improving the thermal conductivity, the heat produced by the absorption of radiation is conducted faster into the nanofluid.

The second preliminary test was when each heat transfer fluid was added to the thermo bank in order to evaluate the heat transfer from the heat exchanger (IC) to the air contained in the dehydration chamber.

Table 1. Specific heat values of each heat transfer fluids under study.

Heat transfer fluid	Cp (J/kg°C)
Oil + NP Ag	3519.41
Oil	2000
Water	4186

Figure 5 shows that after the first 15 minutes have elapsed, a substantial change occurs in the speed of increase of the air temperature in the dehydration chamber. Given its high thermal conductivity, the nanofluid, when passing through a heat exchanger made with metallic tubing (copper), begins to accelerate the heat transfer process to the medium.

3.2. Results of humidity and temperature kinetics in the dehydrated chamber

In this section, the complete operating process (with product) is evaluated, based on the processes of both heat transfer emitted by the heat exchanger, and the refrigeration process (inverse sublimation - fusion) for the extraction of moisture from the product to the three types of heat transfer fluids. To monitor these processes, data logger fitted with sensors of temperature (°C) and humidity (% H) were placed inside the dehydration chamber to record data every 5 minutes simultaneously. The value of solar radiation averaged 820 W/m^2, the experimentation was carried out during the summer months (January-March).

Figure 6 shows the results related to the temperature variation processes. All the samples started from an average temperature of 25 °C, and were taken up to a maximum of 50 °C, this due to the fact that various authors[60,71] have reported that the temperature in a fruit dehydration process should be around 50 — 60 °C, since higher temperatures imply a cellular modification of the fruit and therefore change of organoleptic characteristics.[72]

As observed in Figure 5, the nanofluid has better heat transfer kinetics, the same can be observed in Figure 6, achieving the maximum dehydration temperature in 115 minutes, followed by oil with 140 minutes and finally the water, which took much longer (275 minutes). Time is an important factor in the production process, without neglecting the quality of the dehydrated product, this could also be linked to the fact that longer processes of exposure of the product to high temperatures can have a negative effect on its organoleptic properties. Likewise, the speed of the increase in the temperature of the chamber can be observed based on the growth slope, which showed a better efficiency for the nanofluid. Studies consider

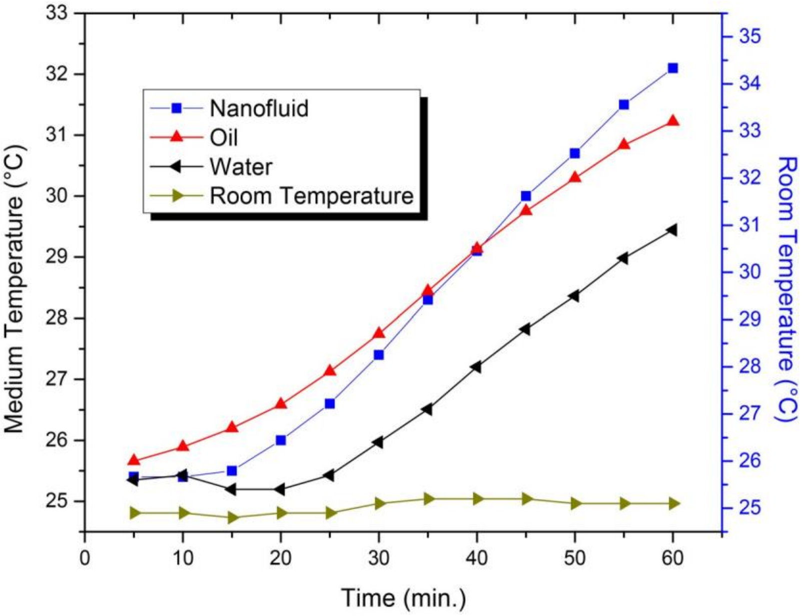

Figure 5. Graph of the preliminary evaluation of the variation of the temperature obtained by heat transfer recorded for each heat transfer fluid.

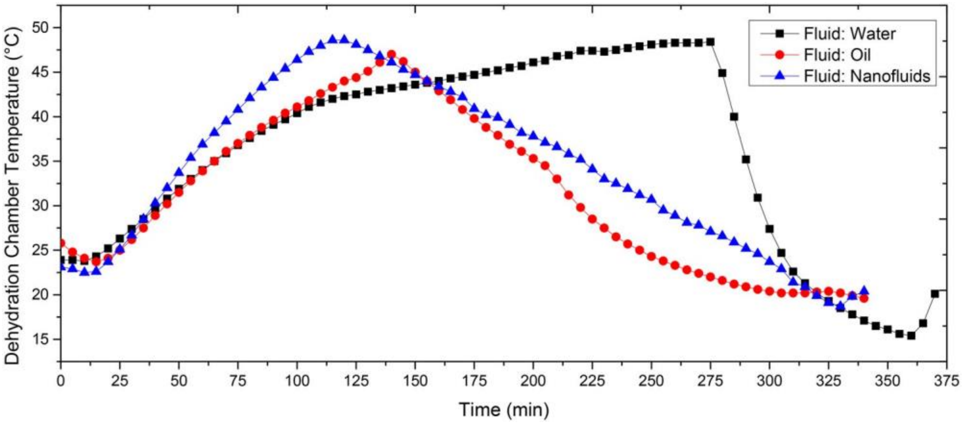

Figure 6. Temperature changes in the dehydration chamber in function of different heat transfer fluids.

that minimizing drying time has an influence on improving product quality.[73]

Once the maximum dehydration temperature had been reached, the refrigeration system was turned on in order for the humidity to be taken to the inverse sublimation-fusion process, this is how the temperature decrease phase begins (in all cases). In the cases of oil and water heat transfer fluids, the decrease was quite rapid, thus limiting gradual handling, and partly motivating the sudden change in temperature; In this sense, the nanofluid showed a better gradual temperature decrease behavior, avoiding structural changes at the biological level of the product being dehydrated, and in turn being reflected in some variation of its organoleptic properties.

In all the graphs one can see a small increase of temperature at the end of the process. This is because in order to remove the dehydrated product (lucuma slices), it is necessary that the temperature be equal to or higher than room temperature, in order to avoid condensation on the surface of the slices. It is worth mentioning that at that stage the pump was turned on (B1), see Figure 1(a), to initiate a process of forced convection of the heat stored in the thermo bank through the heat transfer fluid.

Figure 7 shows the changes in relative humidity in the dehydration chamber for the entire dehydration process. It can be seen that with the increase of temperature in the dehydration chamber, the values of relative humidity tend to decrease. The lowest relative humidity value was 31.3% for the case of the nanofluid, whereas for oil it was 38.1%, and for water 49.1%. In all cases, a small variation in the improvement in the humidity decrease kinetics is evidenced,

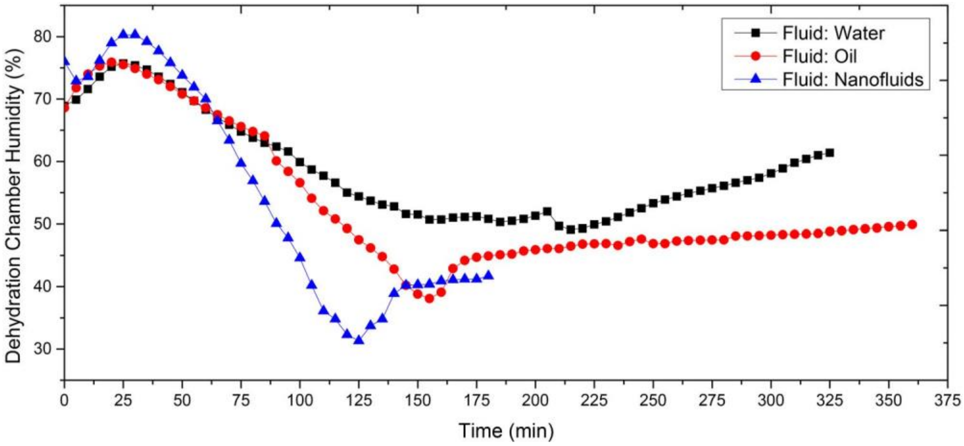

Figure 7. Relative humidity changes in the dehydration chamber in function of different heat transfer fluids.

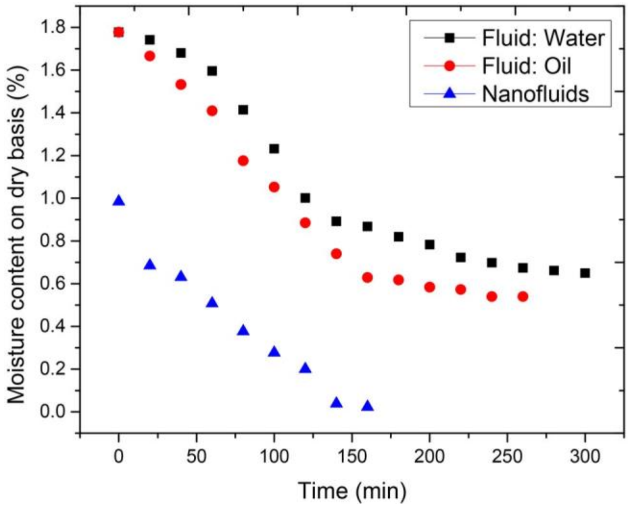

Figure 8. Changes of moisture content of lucuma slices on dry basis.

close to reaching its lowest value in the chamber, this is due to the fact that the refrigeration system initiates the inverse sublimation process - humidity fusion, thus reducing the humidity saturation of the environment of the dehydration chamber; after this, a small increase in humidity is noted, this is due to the fact that the pump (B1) (see Figure 1-a), is turned on to raise the temperature and avoid condensation.

3.3. Drying results

A drying experiment was conducted with an average fresh lucuma pulp mass of 245 grams, with an average initial humidity of 57.5%, and a maximum dehydration temperature of 50 °C.

Figure 8 shows the moisture content on dry basis versus time, where it is evident that the case when using the nanofluid provides a much faster heat transfer to the lucuma sheets in a uniform manner throughout the surface section, this is reflected in the linearity of the decrease in product moisture and the time reached, in this specific case with only 160 minutes reached the lowest moisture value with respect to the other heat transfer fluids, such as oil and water, with times of 260 and 300 minutes respectively. This process was determined by forced convection with an air velocity of 3 m/s at 50 °C.

Considering the changes of moisture in the product shown in Figure 8 there does not appear any occurrence of moisture re-uptake process, without opening the dehydration chamber at any time. As a result, no volatile compounds contributing to the flavor and aroma of lucuma are lost, several authors consider the importance of drying fruits in closed flow systems.[25,26] Moreover, considering that the dehydration process was gradual, there was a lesser risk of damaging the cellular structure of the fruit and releasing the volatile compounds.

3.4. Results of physical and chemical analyses

Prior to the dehydration process, physical and chemical analyses were carried out, in order to characterize the raw samples (Table 2).

For the sake of comparison with other conventional treatments, two samples were added to those subjected to physical and chemical analyses. One sample was labeled Mo and had been sun-dried. The other sample, labeled M4, was a commercial sample of dehydrated lucuma of export quality, brand: Ecoandino – Peru. It originated from 100% organically produced crops without chemical additives and without additional sugar added to the powder sample. The technical sheet of this sample shows compliance with the specifications for organic products of certified export quality.

Table 2. Components of the lucuma fruit.

Analysis	Result
Moisture content	64%
Titratable acidity	1.6
Protein	1.40%
pH	5.38
Fats	0.30%
Carbohydrates	25%
Ash	2.30%
◦Brix (soluble solids)	22.5
Maturity index	16.56

In the latter case, dehydration was obtained using an industrial dehydrator with a heat source provided by liquefied petroleum gas (LPG), and water heating by boiler, whose calorific contribution was transmitted by forced convection to the product.

The sample labeled M1 was that produced with the innovative solar dehydrator equipment using water as heat transfer fluid, the sample M2 was using oil, and sample M3 was using nanofluid. It is worth mentioning that all the analyzes have been standardized according to the same mass (powder), with three repetitions for each sample, therefore, what is presented in a quantified way are the averages of the analyzed values.

Table 3 presents the results of the physical and chemical analyses. As the first parameter is moisture content it appears that for the Mo sample the final moisture value of the product was 27.4%, which indicates that the simple exposure to the sun and in turn the extraction of humidity by evaporation of the sample sent directly to the external environment is not enough to improve the dehydration of the product. The cases of the samples evaluated in the innovative solar dehydration system according to the type of heat transfer fluid show a high efficiency for the M3 sample, where nanofluid was used. This could be expected due to the results of the thermodynamic behavior presented in the section (3.2) were able to better reduce the humidity of the dehydration chamber, and therefore result in a better water extraction from the fruit slice.

The cellular structure of organic products are very sensitive to temperature, causing the destruction of the cell wall and therefore the loss of proteins.[72,74–76] This is evidenced by the fact that the processes with greater exposure to the heat source (as is the case of sample M1) show the lowest result (loss) among the protein values of dehydrated lucuma and in turn a lower value in comparison with the initial sample (fresh fruit, Table 2), the closest protein values in comparison with the fresh fruit sample are for the samples M2 (oil) and M3 (nanofluid). In both cases the dehydration process is gradual and with shorter exposure time. The M4 sample cannot be compared (with respect to a fresh sample) because the initial sample was not available.

Table 3. Physico-chemical composition of lucuma dehydrated by various methods.

Parameter	Mo	M1	M2	M3	M4
Humidity (%)	27.4	39.38	35.04	2.26	8.2
Protein (%)	1.27	0.98	1.4	1.3	1.5
Fats (%)	0.8	0.72	1.15	1.09	0.9
Carbohydrates (%)	42.1	60.2	79.01	54.8	63.7
Ash (%)	2.7	3.0	3.1	3.7	3.08
◦Brix (soluble solids)	26.3	27.5	29.07	30.6	24.1

Regarding soluble solids, it can be seen that in all cases there is an increase in comparison with the fresh fruit sample, the M3 sample being the one with the highest value (influence of nanofluid); in general terms, temperature causes various enzymes to degrade and turn into sugars, which is reflected in the increase in °brix values.

3.5. Organoleptic properties

To assess the organoleptic properties, the sensory evaluation method was used. This involved a population of 15 previously trained panelists, and Friedman's odd numbers were used to compare the treatments and thus evaluate each quality attribute. The evaluation was based on to the following scores: 1 = Poor, 3 = Fair, 5 = Good, 7 = Very Good, and 9 = Excellent. The results are focused on such attributes as flavor, aroma and color. The samples evaluated were the same as those mentioned in Table 3 (5 samples).

The flavor attribute resulted in the statistical value by Friedman ranges T = 46.87, this based on the value of the chi-square distribution table with Tukey's test with a significance level of 5% (a = 0.05) and gl = 4, obtaining $X_{(0.05,4)} = 9.48$; in this sense, as the Friedman rank statistic is greater than the value of the table, the null hypothesis is rejected, and therefore it is concluded that there is enough statistical evidence to accept that at least one of the samples presents a different taste, in in this case, the M3 sample (using nanofluid) obtained the highest score for the attribute in question.

For the aroma attribute, the results applying Friedman ranges show that there is also enough statistical evidence to accept that at least one of the samples presents a different aroma, in this case the values of the significance level and degrees of freedom (gl) were as follows themselves, being the value of T = 62.40. Sample M3 is the one that is also characterized by having a better aroma.

Table 4. Summary of pessimistic and optimistic scenario, for lucuma (thousands of dollars), for Moche, Trujillo-Peru.

Changing cell	Current value	Optimistic lucuma	Pessimistic lucuma
Production volume (Tn)	450	500	320
Sale price	16	20	13
Acquisition of plants	350	450	400
Land	2250	1000	5000
Physical works	95.3	75	100
Machinery and equipment	1064.3	850	1100
Workforce	722.7	680	750
Indirect costs	15.9	12	17000
Variable selling expenses	282.5	280	300
Fixed selling expenses	8.4	7.5	10
Administration expenses	0.8	0.5	1
RESULT CELLS:			
NPV	$15368.8	$23452.6	$6620.5
IRR	41.90%	54.20%	26.40%
ROI	2.9	3.9	1.8
Sale price	4.04	3.32	6.35
DI	1.9	2.9	0.78

A similar case was for the color attribute, obtaining a value of T = 47.72, this compared to the value of the chi-square distribution function table (9.48), the result is greater to conclude that one of the samples presents a different color, being the best value obtained for sample M3.

3.6. Economic analysis of the drying system

An estimated and proportional calculation has been made for the development of an economic analysis of the costs involved in the production process, through the application of a sensitivity analysis. For this study, the production of lucuma fruit (annual) in the district of Moche, located in the province of Trujillo, Peru, has been taken as a reference. Table 4 shows the current data (as a reference) and compares them with respect to two scenarios (optimistic and pessimistic). For the analysis, the most important conditions of the productive zone were considered, as well as the management of the independent variables of the model, and the behavior of the dependent variables such as: Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (ROI), Payback Period (PR) and Desirability Index (DI).

In this sense, the results show that even under pessimistic conditions (conditions of uncertainty) the productive proposal is still profitable, in the case of the optimistic scenario, the profitability is better and higher, with IRR and NPV values of 54.2% and 23452.6 thousand dollars.

4. Conclusions

The research presents an innovative closed flow solar dehydration system is efficient, since it adds calorific inputs (trombe wall and parabolic cylindrical collector) that allow the transfer of heat to be uniform. Likewise, the refrigeration system planned to generate the reverse sublimation process - moisture fusion succeeded to extract the water contained in the product, avoiding opening the principal chamber and therefore losing volatile compounds that provide the dehydrated with attributes such as flavor and aroma. The use of the heat transfer fluid: nanofluid optimized the time to achieve the temperature of 50 °C and transfer the heat uniformly, thus avoiding a prolonged exposure of the product, this is evidenced in the physical-chemical results, where the slice obtained in the mentioned process has a better characteristic; likewise, there is a positive impact on the organoleptic evaluation, where attributes are better compared to the other samples evaluated. Therefore, this technology can be used to minimize the energy consumption of dehydration and/or lyophilization systems, reducing production costs and CO_2 emissions. The economic analysis shows that even under pessimistic conditions (conditions of uncertainty) the production proposal is still profitable; in the case of the optimistic scenario, profitability is better and higher, with IRR and NPV values of 54.2% and US$23,452.6 thousand. This would be an advantage over currently used drying/dehydrating systems that are often consuming fossil fuels. Moreover, products with better organoleptic characteristics could be produced thanks to the system described in this study.

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Disclosure of interest statement

The authors declared that they have no conflicts of interest to this work.

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