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The advantages of the Refractance Window method of dehydrating fresh tomato slices and the relevant characteristics thereof

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ABSTRACT

Tomato slices were dried via hot-air drying and refractance window technology under 75 ºC and 90 ºC respectively. Energy consumptions were evaluated as regards both drying methods and their rates of drying were plotted in diagrams. Furthermore, the physical and chemical properties of the dehydrated tomato slices were assessed. These properties include the changes in the diameter of the slices, the total phenol content and also the colour of slices. Results show that the process of dehydration occurs at a non-linear rate regarding both drying techniques. The refractance window technique is superior to hot-air drying because it operates within a shorter amount of time, can consume less energy and can better maintain the quality of tomato slices through the dehydration process. Results pertaining to the physical and chemical changes indicate that refractance window (RW) drying can be chosen in preference to hot-air drying because thereupon the dried tomato slices exhibit better qualities.

KEYWORDS: drying, energy consumption, hot-air drying, refractance window (RW), tomato slices

1. INTRODUCTION

Food drying is one of the most important processes in the food industry, and it demands various levels of energy to produce commercially dried food products of high quality [12]. A powerful precursor to food preservation, the process of drying is superior to many other methods of preserving perishables since the dehydrated product can be stored for longer durations, is more resistant to microbial spoilage, can be consumed easily, needs less cost for transport, generates more added value and can take on appealing variations [18]. Nevertheless, the process of drying foods has its own turning points. It is considered as a delicate process wherein adverse effects on the physical and chemical properties can become problematic due to intense heat and water loss that is imposed on the food product. Most food products are susceptible to heat, which causes the food to undergo unfavorable changes such as oxidation, the occurrence of unnatural colors, reduced size and volume and also qualitative deteriorations in the food texture due to water loss. Such changes can further affect nutritional qualities adversely [10]. On the other hand, the demand for dried foods is increasing as a result of the ever-changing lifestyles in societies.

The tomato (Lycopersicon esculentum Mill.) is the second most common vegetable product in the world. Tomatoes comprise a large proportion of the vegetable diet in many cultures [20]. The nutritional role of tomatoes has inspired the food industry to invent more efficient food technologies so as to prevent oxidative damages and the degradation of lycopene while tomatoes are stored [7]. The process of drying tomatoes is aimed at increasing their storage period besides providing the opportunity to produce a powdered additive that can be used extensively in cooking [21]. The drying of tomatoes has to take place steadily; therefore it is recommended that the process and technique of drying should be accompanied by precision.

Drying is a common process and yet it is energy-consuming; therefore, one's proper choice of the drying technique is a decisive step towards economic savings. Generally, the concept of drying implies that a food product passes through a current of hot or warm air for dehydration to happen [15]. However the amount of energy needed to create the hot or warm air is a questionable area of discussion, and it is endeavored to move towards techniques that can reduce energy costs besides maintaining the food quality upon dehydration. Towards the end of the 1990s, the Refractance Window (RW) system was invented by the MCD technology company, Tacoma. In this method, the fresh food product is spread on an endless circuit of polyester belt and is exposed to heat, which is provided by

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hot water (90 ºC) which, in turn, circulates in the system. Therefore the heat of the water is recycled besides being strengthened whenever the water temperature falls [22].

Several researchers have previously worked on the RW system. For instance, in 2003, the puree of pumpkins was brought on to this drying method. The moisture of the samples fell from 80% to 5% through 95 ºC and a drying time of 5 minutes [13]. In another experiment, it was discovered that the puree of banana retains its nutritional qualities more when treated with RW, in comparison to other methods such as microwave, Radio frequencies (RF), infrared, ohmic contact, pulse electric field, high pressures and high-intensity pulsed light [11]. Furthermore, researchers have evaluated the output of the RW method when drying the samples of ketchup sauce and carrot puree. They found that the RW can dehydrate food products within shorter amounts of time and also by consuming less energy, in contrast to the freeze drier, and they also found that the physical and chemical food properties of RW products can rival that of the freeze drier products [4]. With regard to tomato slices, the process of drying has previously been carried out in studies via hot-air drying [9], rotating tray drying [19], solar tunnel food drier [17] and also by the microwave [24]. However, there is no report on the drying of tomato slices via RW, which is why this paper aims to compare the RW output to the output of hot-air drying. Various drying times and temperatures have been used here with so as to establish an optimum drying procedure for tomato slices via RW. The physical and chemical properties of the dried products obtained from both methods have been compared with each other, and their levels of energy consumptions have been evaluated.

2. MATERIALS AND METHODS

2.1. Sample preparation

Tomatoes were purchased from the local market and were washed thoroughly before being kept in the fridge (4 ºC) and then sliced horizontally to rear 2 mm slices. Tomatoes of uniform shapes and sizes were used for slicing.

2.2.1. Driers

2.2.2. Hot-air drier

The department of food science and technology of Shiraz University provided a hot-air drier which measured 30cm * 45cm * 55cm. The initial temperature of the hot air entering the drier was set at 75 ºC and 90 ºC. Following dehydration, the samples were packed in polyethylene bags and were kept in cold storage at 4 ºC.

2.2.3. Refractance Window drier

The RW drier of Shiraz University was used for this purpose. The system was adjusted at 75 ºC and 90 ºC. The 2mm tomato slices were placed on the polyester belt of the RW. The rotating speed of the RW fan was set to generate an air velocity of 0.1 m/s, with the air current flowing close to the polyester film. Following dehydration, the samples were separated from the polyester belt via a blade. They were packed in polyethylene bags and stored at 4 ºC until further experiments were due.

2.3. Illustrating the curves pertaining to the drying rate

The moisture of the tomato slices was determined via the AOAC method [2] and its amount was calculated via formula no.1 of the moisture base. In order to illustrate the curves relating to moisture and the drying rate, the samples' water content was evaluated every ten minutes throughout the drying process. The relative moisture is calculated when a sample's moisture in any given moment is divided by its initial moisture (of the dry base moisture). The amount of moisture of the dry base was calculated by formula no.2. The curve for the drying rate was plotted every ten minutes, according to the moisture content. Formula 3 demonstrates how to calculate the rate of drying [9].

Eq. 1. $\%M_{wb} = ((W_i - W_d)/ W_i) *100$

Eq. 2. $\%M_{db} = M_{wb}/(1- M_{wb})$

Eq. 3. $DR = (W_{i-1} - W_i)/(W_d * \Delta t)$

M_{wb} is the moisture of the water base, M_{db} is the moisture of the dry base, DR is the drying rate, W_d is the ultimate weight of the sample based on grams, W_i is the sample's weight at t_i (presented in minutes) and Δt is the time between t_i-1 and t_i.

2.4 Assessment of colour

Colours of the samples were recorded by taking digital photographs in a special chamber under controlled conditions and the analysis of the photographs was done via the CS2 Photoshop software. Parameter a represents redness and greenness (+a is the level of redness and -a is the level of greenness). Parameter b shows the yellowness and blueness of the sample (+b is the yellowness and -b is the blueness). Parameter L represents the brightness of the sample, (a totally black sample gets a zero and a totally white sample gets 100). Photographs were taken inside a chamber measuring 50 cm * 50 cm * 50 cm. Inside the chamber was a white background and the angle between the camera lens and the axis of the light source was approximately 45º. Once the parameters (L, a and b) were extracted, the changes in colour (ΔE) could then be worked out [25].

Eq. 4. $$\Delta E = \sqrt{(L_i - L_o)^2 + (a_i - a_o)^2 + (b_i - b_o)^2}$$

Subscript 'i' represents the value read from any given sample and the 'o' subscript shows the value read from the control group.

2.5. Total phenol content

A spectrophotometer was used accordingly, along with the Folin and Ciocalteu method for phenol measurement. Ten grams of the dried powder of the tomato slices were shaken in 1L of water. One milliliter of this was mixed with a milliliter of hydrochloride acid (6 M) and 5 ml of methanol (75%). This solution was placed in a bath of hot water (90 ºC). The solution was then cooled down to reach air temperature and was diluted with water to reach a volume of 10 ml. The solution was later diluted further with Folin and Ciocalteu ten times. Then 15 ml of Sodium carbonate (7g/100 ml) was added to the solution and finally it was diluted with water to reach 100 ml. The frequency of light absorption by the spectrophotometer device was read at 760 nm in comparison to the control group [23].

2.6. Assessment of energy consumption

A mono-phase digital counter was used to measure the energies consumed by each drier. The digital counters were connected to mono-phase electricity and each drier was linked to the drier separately. The driers were turned on and the digits on the electric counter were noted down when the driers had reached their stable temperatures. The digits on the electric counter were also recorded after the process of drying had finished. Therefore the energy consumptions of the driers were calculated by subtracting the primary digits from the secondary ones, expressed in kWh.

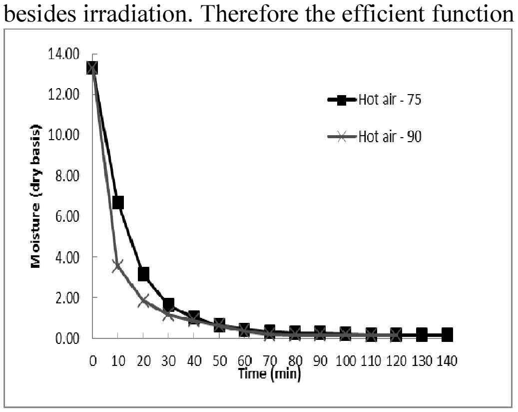
2.7. Statistical analysis

The experiment was laid out in a completely randomized design which had three replications. The Duncan test was used to evaluate the significant differences between the means ($p<0.05$). The SPSS 18 software was used for data analysis.

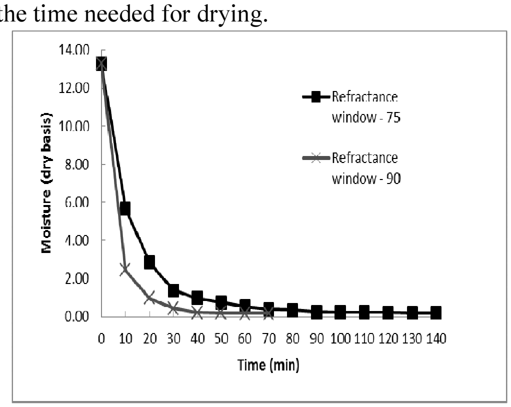
RESULTS AND DISCUSSION

3.1. The drying rate

Figures 1 and 2 present the moisture content and the drying rate observed in the hot-air drier and the RW, both under 75 ºC and 90 ºC. The initial moisture of the tomato slices were 13.29 ± 0.25 of the dry base which ultimately reached 0.16 ± 0.02 grams via both driers. The time needed for samples to reach the dry state in the hot-air drier was 140 minutes at 75 ºC and 120 min at 90 ºC. However, the RW drier took 140 min to dry the samples at 75 ºC, but then only 70 min to dry them at 90 ºC. The reason why the RW drier takes half the time to dry samples at 90 ºC is because hot water irradiates upon the samples directly. In this method, heat is transferred to samples via conduction and convection besides irradiation. Therefore the efficient function reduces the time needed for drying.



(a)



(b)

Figure 1. The curve pertaining to moisture change when drying at 75 ºC and 90 ºC (a: the hot-air drier; b: the RW).

It is evident from the curves in figure 1 that the process of dehydration adopts a declining trend, and that drying does not occur at a steady rate, in the case of both driers. Previous reports also indicate that drying via the thin layer system or the hot-air drier tends to exhibit a declining trend [9, 6]. Other experiments that have been carried out via the rotating-tray drier yielded similar results, while stating that the degree of temperature inside the drier exerts the greatest influence on the amount of water molecules escaping from the samples [19]. The drying of strawberry and carrot purees via RW shows that the release of water molecules happens at a steady rate and has a declining trend which may be due to the thinness of the samples' exterior layers [1]. As is evident from the figures, the rate of dying is faster in the early minutes of the drying process, whereas it gets slower and slower towards the end of the operation. This reduction in the drying rate may be due to the reduction in heat conductivity because of less moisture in the samples [1].

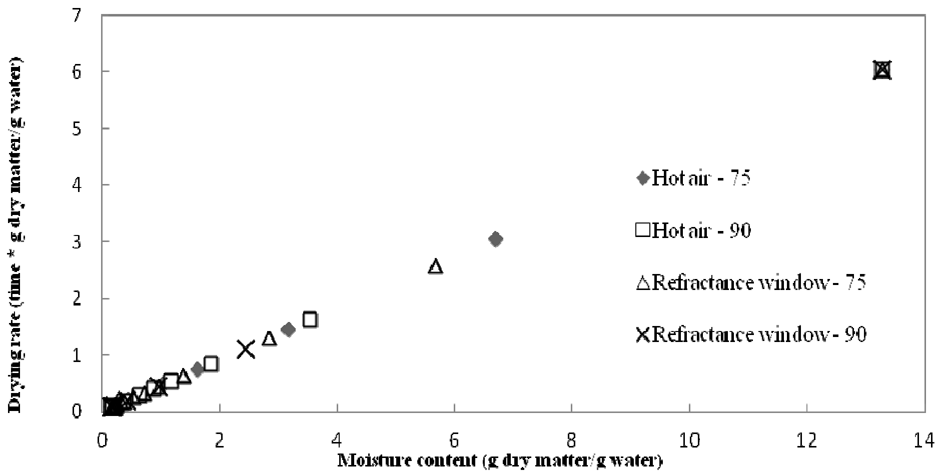


Figure 2. The drying rate at 75 ºC and 90 ºC in the hot-air drier and the RW.

3.2. The assessment of colour

Results pertaining to colour are presented in figures 3 and 4. There was no significant difference in the brightness (L*) of the dried samples, under 75 ºC and 90 ºC in both driers. Both treatments caused the appearance of brown pigments which is due to the chemical interaction between reductive sugars and amino acids. Arsalan and Özcan achieved similar results in 2011 when they were drying hot peppers via sun-drying, hot-air drying and the microwave [3]. Another reason for decolouration and the regression of brightness can be directly because of moisture loss.

The high value of the a* parameter shows the greatest degree of the tomatoes' redness prior to drying. This colour declined in its strength, however, when the slices were exposed to the hot-air drier and the RW (figure 3b). This declining is similar to the declining of the anthocyanin content as is depicted in figure 3c. With regard to redness, there was no significant difference between the dried samples treated under 75 ºC and 90 ºC. However, natural redness was less prominent in those slices that had been dried in the hot-air drier because the longer duration of exposure to heat caused more severe degradations in the red pigments and their transformation into unnatural pigments. The occurrence of non-enzymatic reactions is further reasons [8].

The b* parameter indicates the yellowness of the samples. Apart from the RW treatment under 90 ºC, the other treatments exhibited increases in their amount of yellowness. The yellowest of all the dried samples were the ones dried at 75 ºC with the hot-air drier (figure 3c). Meanwhile, those slices that had been dried at 90 ºC via RW were not significantly different from the fresh slices as regards their yellowness. Therefore, by using the RW, the dry product will have a higher degree of resemblance with the fresh product in terms of yellowness.

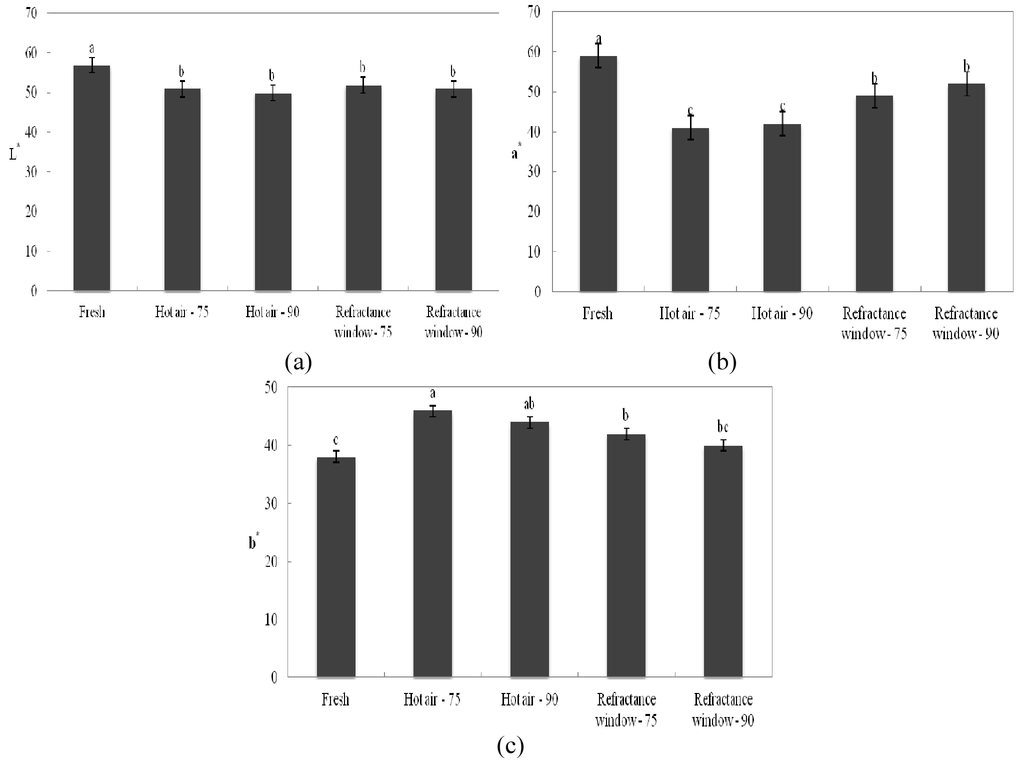


Figure 3. Parameters of colour analysis for the fresh and dried slices of tomato, dried at 75 ºC and 90 ºC via the hot-air drier and the RW. (a), also shown as L*, demonstrates the colour brightness. (b), also shown as a*, is the redness. (c), also shown as b*, is the yellowness of the samples. The reoccurrence of letters in the figure imply that there is no significance at $p<0.05$.

The evaluation of the total changes in colour (ΔE) shows that the biggest change happened in the case of the hot-air drier operating at 75 ºC, while the smallest change was in the RW operating at 90 ºC (figure 5). The hot-air drier took longer to dry at 75 ºC, which is why its samples exhibited the biggest total changes in colour.

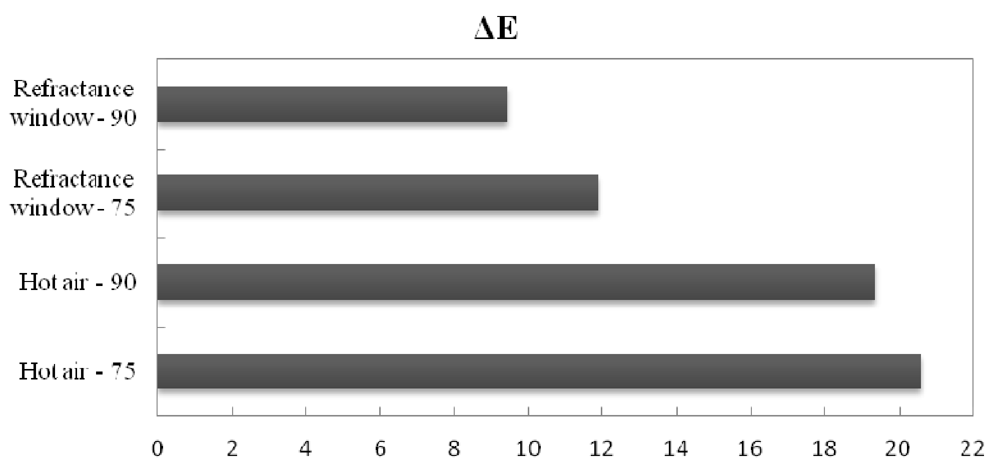


Figure 4. The total changes in colour (ΔE) of the dried samples treated with 75 ºC and 90 ºC via the hot-air drier and the RW, drawn against the benchmark of fresh samples.

3.3. Total phenol content

Figure 6 shows that the least chemical alteration — with an emphasis on phenol content — was observed in samples dried via the RW at 90 ºC because that condition does not substantially degrade the samples' susceptible chemicals. On the other hand, samples' treated with 90 ºC via the hot-air drier exhibited the most severe reduction in phenol content (figure 5). Generally, higher temperatures have greater ability in degrading natural compounds such as flavonoids and phenols. Besides, higher temperatures accelerate the rate of both enzymatic and non-enzymatic reactions, and such reactions further act to degrade the product's natural compounds [5].

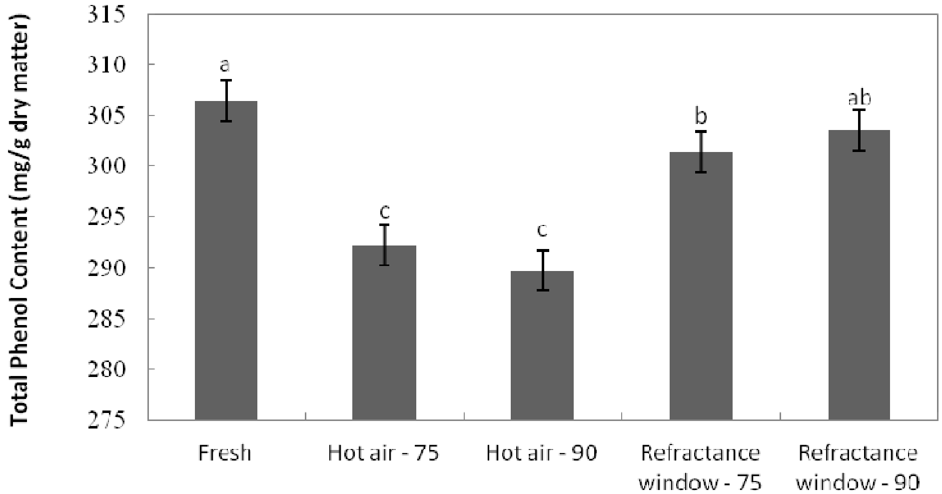


Figure 5. The total phenol content of fresh samples and the dried are depicted with differences being noticeable between the two temperatures and the two methods, expressed in milligrams of gallic acid equivalent. Reoccurring letters beside the digits denote the absence of significance at $p<0.05$.

Figures 5 and 6 clearly show that the phenol content of those samples that had been dried at 75 ºC and 90 ºC via the hot-air drier did not vary substantially. The phenol content of all the dried samples is less than their fresh counterparts, but the RW could better maintain the phenol content through the drying process. RW did not cause any significant difference in the phenol content of dried samples that had been dried at its 75 ºC and 90 ºC. Neither was there a significant difference between the phenol of the fresh samples and the dried samples. This is because of the reduction in the amount of time needed for samples to dry in the RW and also because of its optimized energy consumption. Intense heat can make tomatoes build up on the concentrations of their simple phenol compounds such as chlorogenic acid, caffeic acid and para-coumaric acid. However, there is a reduction in the concentration of the complex phenol compounds such as furoic acid, rutin and naringin. Therefore, the general compositional concentration of phenols will seem to have remained constant after the outbreak of intense heat [16, 19].

3.4. Energy consumption

Figure 6 is explicit enough to illustrate that the RW needs less energy to dehydrate 100 grams of fresh samples which is because of its shorter operation time. Contrariwise, the greatest energy consumption is attributed to the hot-air drier operating at 90 ºC. When discussing the hot-air drier, it takes a shorter amount of time for samples to dry at 90 ºC, but this also consumes more energy compared to the operation at 75 ºC. Therefore the energy consumption by the hot-air drier is more immense when operating at 90 ºC, even though its operation time is shorter than that of the 75 ºC. The heater's excessive demand for energy is the reason behind this contrast.

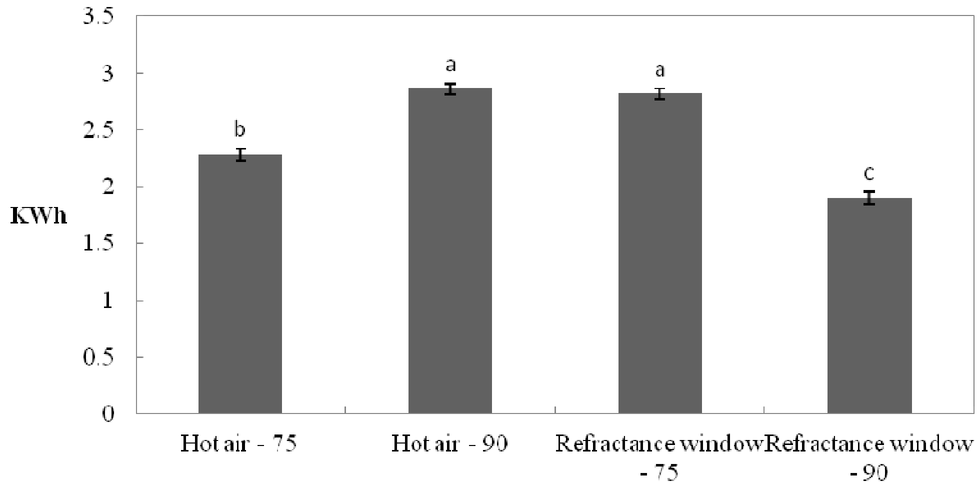


Figure 6. Energy consumption for the dehydration of 100 grams of fresh tomato slices via the hot-air drier and the RW, operating at 75 ºC and 90 ºC.

Conclusion

It is concluded that the RW takes a shorter amount of time to dry fresh samples of tomato, and this gives it an overwhelming advantage over the hot-air drier. The physical and chemical properties of the tomato slices were better maintained when treated with the RW, compared to the hot-air drier. Total changes in the colour of the slices after dehydration was one of the traits in question, besides the fluctuations in total phenol content and the roughness that was acquired by the surface of the products as a result of dehydration. All of these characteristics were more favourable thanks to the RW, which consumes less energy and can yield high-quality dry products.

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