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The Effects of Thermal and Pulsed Electric Field Processing on the Physicochemical and Microbial Properties of a High-Fiber, Nutritious Beverage from a Milk-Based Date Powder

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Abstract: The effects of pulsed electric field treatment and thermal pasteurization on the microbial and physical properties of a high-fiber, nutritional milk-based beverage made with date powder were studied. Four ratios of date powder (10, 15, 20, and 25 *w*/*w*) were added to the milk, which was then kept at 5 °C for 6 days for the thermal pasteurization and the control treatments. The pulsed electric field treatment had three levels of pulses (20, 50, and 80 pulses) and four ratios of date powder, 10, 15, 20, and 25% (*w*/*w*), and then kept at 5 °C for 6 days. The samples were evaluated for the pH, total soluble solids (TSS), total color difference (ΔE), and total viable count (TVC) during their shelf life. The pH values of the beverages in the control treatment were 5.58, 5.45, 5.33, and 5.29 and 6.68, 6.48, 6.26, and 5.87 in the thermal treatment after 6 days, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively. The pH values of the beverages in the pulsed electric field treatment were 6.8, 6.64, 6.56, and 6.28 at 80 pulses after 6 days, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively. The TVCs in the control treatment were 6.2, 5.44, 4.5, and 3.94 log10 CFU/mL and 4.02, 3.92, 3.54, and 3.31 log10 CFU/mL in the thermal treatment after 6 days, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively. The TVCs of the beverages in the pulsed electric field treatment were 1.53, 1.11, 0.665, and 0.511 log10 CFU/mL at 80 pulses after 6 days, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively. This shows that following treatment with a pulsed electric field at 80 pulses, a milk-based drink with date powder and no preservatives can be kept at 5 °C for up to 6 days.

Keywords: thermal process; milk; date powder; PEF; non-thermal process

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1. Introduction

Date palm fruits (*Phoenix dactylifera* Linnaeus) are consumed fresh or dried or are prepared in various ways. Some date products include date honey, date sugar, date vinegar, and date wine (made from date fruit juice). The most popular commercial date products are date juice (primary product), pressed cake (byproduct), and date syrup [1]. Dates are significant for human nutrition and health due to their vast array of healthy nutrients. Dates are rich in antioxidants, such as selenium, phenolics, and carotenoids [2]. Furthermore, dates are an excellent source of quick energy due to their high carbohydrate content (70–80%), primarily fructose and glucose, which are readily absorbed by the body [3].

Many investigations into the functional qualities of dates and their byproducts have been conducted. Studies have discovered that the amount of dietary fiber in 13 kinds of date palms ranges from 8.1% to 12.7% (dry matter) [4].

Dates are one of the most important fruits in the Kingdom of Saudi Arabia for historical, economic, and consumption purposes. Powders have been introduced into many foods in recent periods, such as pastries, juices, and flavored milks. Dates contain many nutrients, such as vitamins, minerals, sugars, and fiber, hence their importance in the production of powders.

Chocolate-flavored milk is one of the most common and popular milk drinks and is the preferred drink by 90% of children [5]. Chocolate-flavored milk has also been widely popular among consumers worldwide [6]. Many milk drinks flavored with chocolate, vanilla, strawberries, and bananas have been developed to feed military personnel [7]. Date powders contain many nutrients, such as vitamins, minerals, sugars, and fiber, hence their importance. Consumers today tend to choose beverages for their nutritional, functional, and sensory attributes, such as color, aroma, and taste, and the safety of healthy beverages [8].

One of the best ways to destroy undesirable germs in liquid meals is with thermal pasteurization. Liquid foods that have been pasteurized are safer and have a longer shelf life. The most popular technique for prolonging the shelf life of vegetable and fruit juices is with conventional thermal pasteurization, which uses a mathematical formula to ensure the safety of the final product [8]. Theoretically, this is a combination of the time–temperature profile and microbial destruction/inactivation. The design of the thermal processing is usually chosen to maximize microbial inactivation with a minimal impact on the product quality [9]. Apple juice is traditionally thermally pasteurized using plate heat exchangers and tunnel pasteurizers. Thermal pasteurization can effectively extend the shelf life of apple juice [10]. The contamination of beverages with microbes could take place during the handling of the beverage by operatives. The pathogens commonly found on human skin and tools can be transferred to foods if good hygienic practices are not followed. *Staphylococcus aureus* is a gram-positive coccus that produces clusters like grapes. This bacterium is mesophilic, catalase-positive, oxidase-negative, and facultatively anaerobic. It grows at temperatures between 7 °C and 48 °C and pH levels between 4.2 and 9.3. It is distinguished by its halotolerance, corresponding to minimum water activity (a_w) values between 0.83 and 0.85 [11,12]. Strains of these bacteria are distinguished by their ability to create heat-stable enterotoxins with a_w values as low as 0.86 under aerobic circumstances.

It is possible to destroy undesirable, harmful, and spoilage microorganisms in food using pulsed electric fields (PEF) technology. Without significantly compromising their nutritional qualities, PEF treatment is effective enough to kill microorganisms in fruit juices at levels comparable to those attained via heat pasteurization [13]. The inactivation of pathogenic bacteria and the decrease in spoilage microorganisms in milk have demonstrated the benefits of using pulsed electric fields (PEF) technology [14,15]. Additionally, it might be possible to prolong the shelf life of milk with PEF by preventing mesophilic bacteria from growing, while very slightly compromising the product's quality [16]. A fluid medium that is placed between two electrodes is subjected to high voltage pulses in the pulsed electric field (PEF), which is mostly a non-thermal process [17].

Therefore, this current study was designed to examine the survival and growth potential of total viable counts (TVC), pH, TSS, and color difference (ΔE) in a stored beverage from milk-based date powder. This study will help to understand the effect of the thermal pasteurization process and non-thermal pasteurization using the pulsed electric fields (PEF) of beverage, and the ratio of date powder to milk on the growth of total counts in a beverage from milk-based date powder without adding any preservatives during shelf life.

2. Materials and Methods

2.1. Prepare the Beverage

The date powder was purchased from a local market in Al-Qassim, Saudi Arabia. The date powder was placed in sterile polythene bags and stored at 5 °C until used [18].

The beverage was prepared with four additions of the date powder (10, 15, 20, and 25% (*w*/*w*)). The powder was added to low-fat cow milk and mixed in an electric mixer (Type: T2, MACAP, Maerne, Italy) for two minutes. The beverage samples were treated in the outlined procedure below.

2.2. Control Treatment

The milk-based beverage made with date powder without any treatment was used as the control. The beverage samples (unpasteurized and pasteurized) were poured into sterile 50 mL jars. Immediately after filling, the jars were stored at 5 °C for 6 days. The beverage samples were evaluated in triplicate for the total viable counts (TVC), pH, TSS, and color difference (ΔE) after 2, 4, and 6 days of storage.

2.3. Pasteurization (Thermal Treatment)

The milk-based beverage made with date powder was pasteurized according to the Gulf Standard for "Pasteurized Milk" [19]. The beverage was pasteurized at 63 °C for 30 min (low-temperature long-time pasteurization (LTLT)), then immediately cooled to a temperature not less than 4 °C. This method is efficient in destroying all vegetative forms of microorganisms and is better at preserving some of the biological components of the beverage.

2.4. Pulsed Electric Field (PEF)

Pulsed electric field (PEF) processing with minimal energy input is a non-thermal preserving method. In the PEF method, food is treated in a chamber containing two electrodes that emit brief electric pulses. A pilot scale pulsed electric field generator model JSV-20-21/02 (Thane, Maharashtra, India) was used for the PEF treatment. The treatment device comprised a chamber containing a 1 L cup. The beverage temperature was at room temperature and tested at 40 kV cm^{-2} [20] with a pulse-off time of 20 µs and the No. of pulses at 20, 50, and 80 pulses. The pasteurized beverage samples were poured into sterile 50 mL jars, which were immediately stored at (5 °C) for six days. The samples were evaluated in triplicate for the total viable count (TVC), pH, color change (ΔE), and total soluble solids (TSS) at intervals of 2, 4, and 6 days of storage.

2.5. Determination of the pH of the Beverage

The milk-based beverage made with date powder was measured at 2-day intervals using a pH meter to estimate its pH (Jenway, Model 3510, pH Meter, Designed and Manufactured in the Stafford, UK) in triplicate.

2.6. Color

The color parameter of a beverage was determined by measuring the sample's color before and after treatment using a tool from Nix Sensor Ltd. (175 Longwood Road South, Suite 408A, Hamilton, ON, Canada). Basic color parameters for a^* redness, b^* (yellowness), and L^* (lightness) were measured in triplicate. Using the following equation, the total color difference (ΔE) was determined:

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2}$$

where the subscript '0' indicates the initial color of milk, and L, a, and b are the color parameters of the beverage.

2.7. Total Soluble Solids (TSS)

The total soluble solid content of the beverage was determined with an RFM Refractometer (Model: ATAGO-28E, ATAGO, Tokyo, Japan) fitted with a scale measuring the percentage of sugar, which is expressed as °Brix.

2.8. Total Viable Count of Bacteria

In accordance with the Association of Official Analytical Chemists [21], 1 mL of the milk–date beverage was mixed with 9 mL of a 0.85% NaCl sterile solution. The samples were shaken carefully. A suitable serial dilution of 10^{-1}–10^{-4} was prepared, and 1 mL of the appropriate dilution was added to 10 mL of a sterilized and chilled nutrient agar (45 °C) in sterilized Petri dishes (CM0309, Oxoid, Basingstoke, UK). The dishes were left to incubate at 35 °C for 24–48 h, and the TVC was counted and expressed as CFU/mL.

2.9. Statistical Analysis

The data from each treatment's triplicate samples were collected and statistically analyzed. Utilizing the SPSS software version 18.0 (SPSS Inc., Chicago, IL, USA), the microbial and physical quality attributes of milk–date powder beverages were statistically analyzed. An analysis of variance (ANOVA) was used to examine the quadratic, interaction, and linear effects of the independent variables (No. of pulses, powder ratio, and storage time) on the responses (TSS, pH, ΔE, and the growth of total viable counts). Acceptable significance levels for the models were $p < 0.001$, $p < 0.01$, and $p < 0.05$.

3. Results and Discussion

The results for the pH values while in storage are shown in Figure 1a–e for the milk-based beverages made with date powder. Higher percentages of powder led to declines in the pH of the untreated and treated beverage samples. We observed that the decline rates for the pH values of the untreated beverages and those treated with thermal pasteurization (Figure 1a,b) were greater than the beverages treated with the pulsed electric field, especially at 80 pulses after 6 days (Figure 1e). The decline rates for the untreated samples were 11.06, 11.58, 12.68, and 11.94, with powder ratios of 10, 15, 20, and 25% (w/w), respectively (Figure 1a). The decline rates for the thermally pasteurized samples (Figure 1b) were 6.67, 8.45, 10.72, and 14.6, with powder ratios of 10, 15, 20, and 25% (w/w), respectively. The decline rates were recorded at 6.59, 8.2, 7.74, and 3.97 for the samples treated with the pulsed electric field (Figure 1e) at 80 pulses after 6 days, with powder ratios of 10, 15, 20, and 25% (w/w), respectively. Samples treated with the PEF at 80 pulses showed a slower decrease in pH compared to samples that were untreated, thermal-treated, and treated with the PEF at 20 and 50 pulses. The independent variable (number of pulses) had a positive impact on the pH, i.e., the pH increased with an increase in the number of pulses (Table 1). The number of pulses exhibited significant influences on the pH ($p < 0.001$), while the powder ratio and storage time had a negative effect on the pH ($p < 0.001$), suggesting that increasing the powder ratio and storage time could decrease the pH of the milk–date powder beverage. The storage time had a negative effect on the pH for thermal-treated samples ($p < 0.05$), i.e., the pH decreased with an increase in storage time. The reason for this drop could be the growth of lactobacillus and the production of lactic acid in the milk, in addition to other possible chemical reactions. A similar trend of changes in the pH was noted by Mnkeni and Nyaruhucha, Kamaly, and Niimi and Shiokawa [22–24]. pH is one of the parameters that affect the survival and development of microorganisms during processing and storage [25]. Food processors are interested in determining the pH of a food product and maintaining that pH at a specific level to control microbial development and prevent product degradation [26]. Therefore, the importance of using the pulsed electric field compared to thermal pasteurization for maintaining the pH at the lowest possible rate of change until the end of the shelf life is clear.

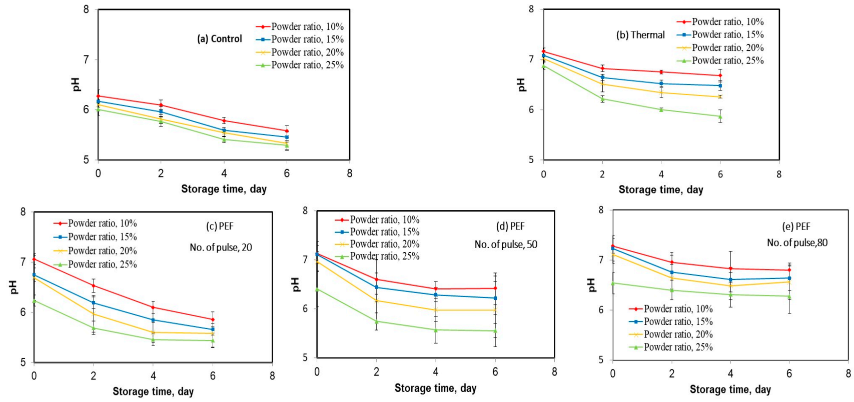

Figure 1. Changes in pH of the beverage prepared from different ratios of the date powder and treated with thermal pasteurization and PEF.

Table 1. Regression coefficients for product responses and process factors.

	Factors	pH	TSS	ΔE	TVC
PEF	***Intercept***				
		6.01	11.233	−2.142	3.62
	Linear				
	Number of pulses (x_1)	0.0173 **	0.044	0.114 ***	0.0053 ***
	Powder ratios (x_2)	0.111 ***	0.561 ***	1.48 ***	−0.317 ***
	Storage time (x_3)	−0.474 ***	−0.437 ***	0.67 ***	1.45 ***
	Interaction				
	X_1X_2	−0.00011	0.0026 *	−0.00321 **	0.0017 **
	X_1X_3	0.00129	0.00291	−0.00203	−0.0094 ***
	X_2X_3	0.00097	0.017	−0.0231 *	−0.008
	Quadratic				
	X_1^2	−0.00011	−0.00085 *	−0.00024	−0.0004 **
	X_2^2	−0.0044 *	−0.0081	−0.0095	0.006 *
	X_3^2	0.045 ***	−0.0088	0.0323	−0.07 ***
Thermal	***Intercept***				
		7.632	15.34	39.29	5.142
	Linear				
	Powder ratios (x_2)	−0.0661	−0.0052 ***	0.768 ***	−0.405 **
	Storage time (x_3)	0.071 *	0.32 ***	0.375 ***	0.404 ***
	Interaction				
	X_2X_3	0.00013	−0.016 *	0.027 **	0.0205 *
	Quadratic				
	X_2^2	0.00155	0.0175 ***	−0.0159 ***	0.0079 *
	X_3^2	−0.0278	−0.0702 **	−0.097 ***	−0.049 *
Control	***Intercept***				
		6.701	12.95	5.34	6.45
	Linear				
	Powder ratios (x_2)	−0.0514 *	0.237 ***	1.036 ***	−0.286 ***
	Storage time (x_3)	−0.0813 ***	0.102 ***	−0.59 ***	0.551 ***
	Interaction				
	X_2X_3	0.00096	−0.0314 **	−0.0142 *	−0.01 **
	Quadratic				
	X_2^2	0.00094	0.01006 *	−0.0202 ***	0.0055 **
	X_3^2	−0.0088	−0.0411	0.114 ***	−0.0152

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The following equation was developed from the results of the pulsed electric field treatment to predict the effects of the number of pulses, powder ratio, and storage time on the pH of milk–date powder beverages:

$$Y_{pH} = 6.00989 + 0.017256X_1 + 0.110764X_2 - 0.474177X_3 - 0.000114X_1X_2 + 0.001289X_1X_3 + 0.000969X_2X_3 - 0.000114X_1^2 - 0.004389X_2^2 + 0.0447251X_3^2$$
$$R^2 = 0.9497$$

where 'x_1' indicates the number of pulses, 'x_2' is the powder ratios, and 'x_3' is the storage time.

The results for the TSS values during storage are shown in Figure 2 for the milk-based beverages made with date powder at different powder ratios and number of pulses. Higher percentages of powder led to increases in the TSS of the untreated and treated beverage samples (Figure 2a–e). The TSS of the untreated and treated beverage samples decreased with storage time. This may be due to the consumption of some sugars by microbes during the storage period, and this is shown by the increase in microbes over time. We observed that the decline rates for the TSS of the untreated beverages and those treated with thermal pasteurization were greater than those of the beverages treated with the pulsed electric field at all levels, especially at 80 pulses after 6 days. The decline rates for the untreated samples were 16.7, 21.2, 21.7, and 20.8, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively (Figure 2a). The decline rates for the thermally pasteurized samples were 17.3, 13.95, 12.09, and 12.75, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively (Figure 2b). The decline rates were recorded at 13.7, 12.4, 5.907, and 3.71 for the samples treated with the pulsed electric field at 80 pulses after 6 days, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively (Figure 2e). The independent variables (number of pulses and storage time) negatively impacted the TSS, i.e., the TSS decreased with an increase in the number of pulses and storage time (Table 1). The number of pulses exhibited a non-significant influence on the TSS, but the storage time exhibited significant influences on the TSS ($p < 0.001$). The powder ratio had a positive effect on the TSS ($p < 0.001$), suggesting that increasing the powder ratio could increase the TSS of the milk–date powder beverage by raising the concentration of sugars and thus total solids. The interaction effect of the number of pulses with the powder ratio positively impacted the TSS ($p < 0.05$), implying that increases in the number of pulses and the powder ratio could elevate the TSS of the beverage. In terms of the quadratic effect, the number of pulses showed a negative impact on the TSS ($p < 0.05$), implying that a rise in this parameter would lead to a decrease in the beverage's TSS.

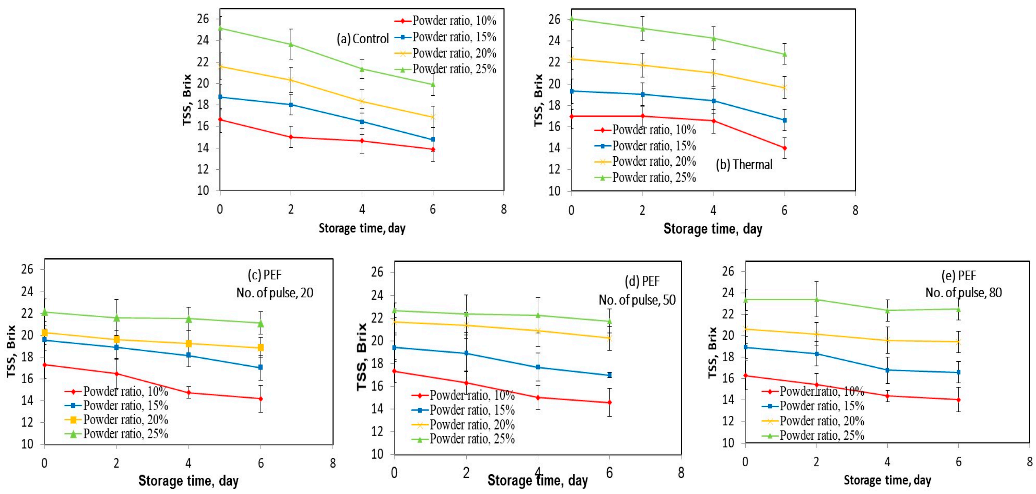

Figure 2. TSS of the beverage was prepared from different ratios of the date powder and treated with thermal pasteurization and PEF.

Storage time had a negative effect on the TSS for thermal-treated samples ($p < 0.001$), i.e., the TSS decreased with an increase in storage time. In contrast, the powder ratio had a positive effect on the TSS ($p < 0.001$), suggesting that increasing the powder ratio could increase the TSS of the milk–date powder beverage. The interaction effects of the powder ratio with storage time negatively impacted the TSS ($p < 0.05$), implying that decreasing the powder ratios with storage time could elevate the TSS of the beverage. In terms of the quadratic effect, storage time negatively impacted the TSS ($p < 0.01$), implying that a rise in this parameter would decrease the beverage's TSS, while the powder ratio positively impacted the TSS ($p < 0.001$).

In agreement with these findings, ref. [27,28] observed a small reduction in the TSS values following the PEF treatment of orange and orange–carrot juice, respectively. The fermentation of carbohydrates by microorganisms could have produced this phenomenon. Increasing the powder ratio brought the beverage's TSS to its highest level at 25% (w/w).

The following equation was developed from the results of the pulsed electric field treatment to predict the effects of the number of pulses, powder ratio, and storage time on the TSS of milk–date powder beverages:

$$Y_{TSS} = 11.23258 + 0.044421X_1 + 0.561403X_2 - 0.436809X_3 + 0.002595X_1X_2 - 0.002912X_1X_3 + 0.016956X_2X_3 - 0.000853X_1^2 - 0.008142X_2^2 - 0.008831X_3^2$$
$$R^2 = 0.9801$$

The results for the ΔE values during storage are shown in Figure 3 for the milk-based beverages made with date powder at different powder ratios and number of pulses. Higher percentages of powder increased the ΔE of the beverage for untreated and treated samples (Figure 3a–e). The ΔE of the untreated beverage samples decreased with storage time (Figure 3a), while the ΔE of the treated beverage samples increased with storage time. We observed that the rate of increase for ΔE of the beverages treated with thermal pasteurization (Figure 3b) was lower than that of the beverages treated with the pulsed electric field at all pulse levels (Figure 3c–e). The decline rates for the untreated samples were 1.4, 4.25, 6.67, and 6.47, with powder ratios of 10, 15, 20, and 25% (w/w), respectively. The rates of increase for the thermally pasteurized samples were 0.52, 2.46, 4.33, and 4.14, with powder ratios of 10, 15, 20, and 25% (w/w), respectively. The rates of increase were recorded at 5.26, 3.64, 7.98, and 10.5 for the samples treated with the pulsed electric field at 80 pulses after 6 days, with powder ratios of 10, 15, 20, and 25% (w/w), respectively.

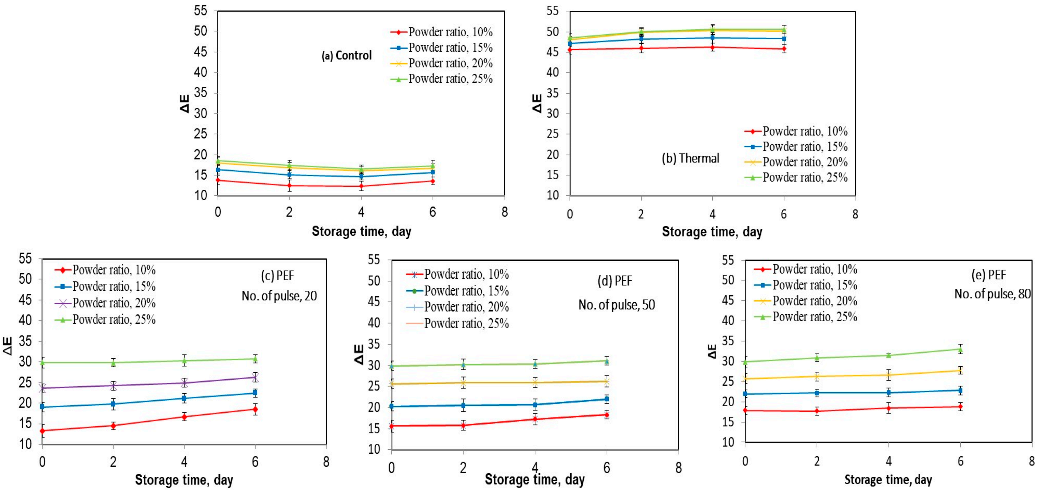

Figure 3. The total color difference of the beverage prepared from different ratios of the date powder and treated with thermal pasteurization and PEF.

The starting values for the ΔE for untreated samples were 13.82, 16.36, 17.9, and 18.52 at powder ratios of 10, 15, 20, and 25% (w/w), respectively. On the other hand, the starting values for the ΔE of samples treated with thermal pasteurization were 45.65, 47.13, 48.1, and 48.55, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively. The starting values for the ΔE of the samples treated with the pulsed electric field were 17.86, 21.99, 25.7, and 29.9, with powder ratios of 10, 15, 20, and 25% (*w*/*w*), respectively, for 80 pulses.

From the above results, we found a significant change in the ΔE values of the heat-treated samples compared to the untreated samples and those treated with a pulsed electric field, and this may be due to the high temperature during the pasteurization process, which affected the color change significantly.

The independent variables (number of pulses, powder ratio, and storage time) had a positive impact on the ΔE, i.e., the ΔE increased with an increase in the number of pulses, powder ratio, and storage time (Table 1). The number of pulses, powder ratio, and storage time exhibited significant influences on the ΔE ($p < 0.001$), suggesting that increasing the number of pulses, powder ratio, and storage time could increase the ΔE of milk–date powder beverages. The decrease in L^* and b^* values indicated that the beverage color became darker. Interestingly, noticeable increases in a^* values indicated an increase in redness [29] and thus a decrease in the ΔE. The interaction effect of the number of pulses with the powder ratio and the powder ratio with storage time negatively impacted the ΔE ($p < 0.01$ and $p < 0.05$, respectively), implying that an increased number of pulses with the powder ratio and the powder ratio with storage time could decrease the ΔE of the beverage. A significant rise in the ΔE was seen after 15 days of storage in a study by [30] on fresh carrot juice treated in a high-voltage electrostatic field and then kept at 4 °C, which is broadly consistent with the results of this study. This may be caused by the PEF's impact on the milk proteins. After synthesizing and binding the dye to the protein, the electric field may break this link, potentially causing the loss of color [5].

The powder ratio and storage time had a positive effect on the ΔE for thermal-treated samples ($p < 0.001$), i.e., the ΔE increased with an increase in the powder ratio and storage time [31]. The interaction effects of the powder ratio with storage time positively impacted the ΔE ($p < 0.01$), implying that an increased powder ratio with storage time could elevate the ΔE of the beverage. In terms of the quadratic effect, powder ratio and storage time negatively impacted the ΔE ($p < 0.001$), implying that a rise in these parameters would decrease the beverage ΔE.

The following equation was developed from the results of the pulsed electric field treatment on the pH and TSS and the low ΔE values of the pulsed electric field compared to thermal pasteurization. The equation can be used to predict the effects of the number of pulses, powder ratio, and storage time on the ΔE of milk–date powder beverages:

$$Y_{\Delta E} = -2.14160 + 0.113833X_1 + 1.48331X_2 + 0.665600X_3 - 0.00321X_1X_2 - 0.002025X_1X_3 - 0.23075X_2X_3 - 0.000235X_1^2 - 0.009527X_2^2 + 0.0322671X_3^2$$
$$R^2 = 0.9956$$

Figure 4 shows the total viable count (TVC) of untreated and thermal-treated samples as affected by the powder ratios and storage time as well as the samples treated with a pulsed electric field as affected by the number of pulses, powder ratios, and storage time. The TVC decreased by increasing the powder ratio (as shown in Figure 4a) for untreated beverages, in which the values for the TVC decreased from 6.2 to 3.94 log10 CFU/mL when the powder ratios increased from 10 to 25% (*w*/*w*) after 6 days. This could be due to the increase in the concentration of sugars and thus total soluble solids, which also affects microbial growth. The increase in storage time led to an increase in the TVC for untreated samples from 4.11 to 6.2 log10 CFU/mL and from 2.82 to 3.94 log10 CFU/mL, with powder ratios of 10 and 25% (*w*/*w*) after 6 days, respectively. Figure 4b shows the TVC as affected by powder ratios and storage time. The TVC decreased by increasing the powder ratio for thermal-treated samples, where the values for the TVC decreased from 4.021 to 3.314 log10 CFU/mL when the powder ratios increased from 10 to 25% (*w*/*w*) after 6 days. The increase in storage time led to an increase in the TVC for thermal-treated samples from 2.06 to 4.021 log10 CFU/mL and from 0.123 to 3.314 log10 CFU/mL for powder ratios 10 and 25% (w/w) after 6 days, respectively. Figure 4c–e shows the TVC as affected by the number of pulses, powder ratios, and storage time. The TVC decreased by increasing the powder ratios for beverages treated with the pulsed electric field. The values for the TVC decreased from 5.2 to 3.69 log10 CFU/mL, 3.99 to 3.01 log10 CFU/mL, and from 1.52 to 0.512 log10 CFU/mL, with the number of pulses at 20, 50, and 80 pulses, respectively, when the powder ratios increased from 10 to 25% (w/w) at the end of the shelf-life period of 6 days. The increase in storage time led to an increase in the TVC, as shown in Figure 4c–e. From the previous results, it is evident that the TVC reached 1.527, 1.108, 0.665, and 0.512 log10 CFU/mL with powder ratios of 10, 15, 20, and 25% (w/w), respectively, at 80 pulses at the end of the shelf-life period of 6 days.

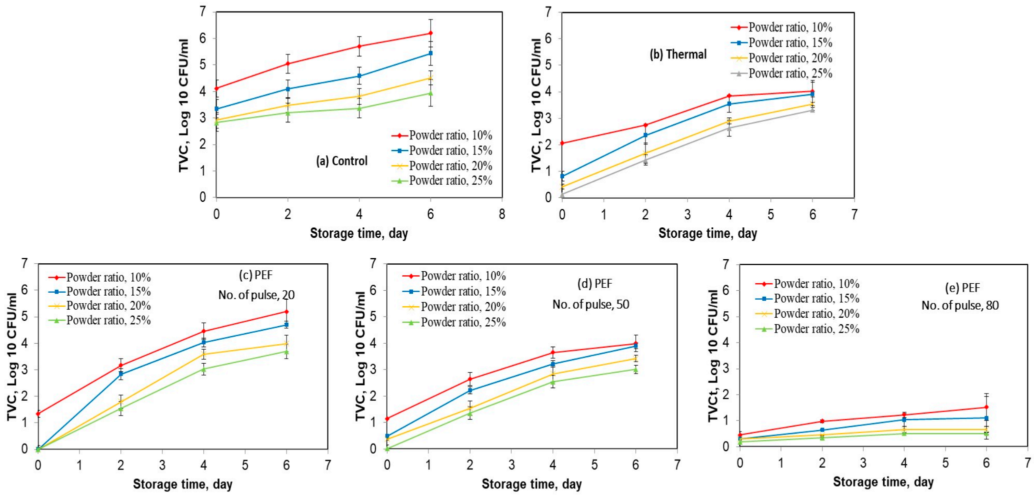

Figure 4. Total viable count of the beverage prepared from different ratios of the date powder and treated with thermal pasteurization and PEF.

The storage time positively affected the TVC for thermal-treated samples ($p < 0.001$), i.e., the TVC increased with an increase in storage time, while the powder ratio negatively affected the TVC ($p < 0.05$), suggesting that increasing the powder ratio could decrease the TVC of milk–date powder beverages. The interaction effects of the powder ratio with storage time positively impacted the TVC ($p < 0.05$), implying that an increased powder ratio with storage time could elevate the TVC of the beverage. In terms of the quadratic effect, storage time negatively impacted the TVC ($p < 0.05$), implying that a rise in this parameter would decrease the beverage TVC, while the powder ratio positively impacted the TVC ($p < 0.05$).

The independent variables (number of pulses and storage time) positively impacted the TVC, i.e., the TVC increased with an increase in the number of pulses and storage time. The number of pulses and storage time positively influenced the TVC ($p < 0.001$). The powder ratio negatively affected the TVC ($p < 0.001$), suggesting that decreasing the powder ratio could increase the TVC of milk–date powder beverages. This could be due to the decrease in the concentration of sugars and thus total soluble solids, which also affects microbial growth. The interaction effect of the number of pulses with the powder ratio positively impacted the TVC ($p < 0.01$), implying that the increased number of pulses with the powder ratio could elevate the TVC of the beverage. The interaction effect of the number of pulses with storage time had negative impacts on the TVC ($p < 0.01$), implying that a decreased number of pulses with the powder ratio could elevate the TVC of the beverage. In terms of the quadratic effect, the number of pulses and storage time negatively impacted the TVC ($p < 0.001$), implying that a rise in this parameter would decrease the beverage's TVC. The powder ratios positively impacted the TVC ($p < 0.05$), implying that the increased powder ratio could elevate the TVC of the beverage. Microorganism inactivation is associated with alterations in and the electromechanical instability of the cell membrane [32]. The primary impact of an electrical field is an increase in the permeability of the membrane due to membrane compression and pore formation. Cell inactivation is believed to be caused by unusual membrane porosity [33]. According to the research described by [34], cell surfaces become rougher as the electric field intensity rises. The pulsed field may generate an electrical–mechanical compression that results in a separation of charges between the interior and exterior of microbial cells in milk, which could be one mechanism for the breakdown of the cell wall. Small holes in the membrane may then result from this separation, allowing the contents of the cell to flow out. Because increasing electrical–mechanical compression causes more cell wall disintegration, an increase in field intensity may, therefore, enhance microbial inactivation.

The following equation was developed from the results of the pulsed electric field treatment to predict the effects of the number of pulses, powder ratio, and storage time on the TVC of milk–date powder beverages:

$$Y_{TVC} = 3.62411 + 0.005338X_1 - 0.317449X_2 + 1.44584X_3 + 0.0016685X_1X_2 - 0.006418X_1X_3 - 0.008016X_2X_3 - 0.000401X_1^2 + 0.0055201X_2^2 - 0.069136X_3^2$$
$$R^2 = 0.9884$$

4. Conclusions

The key goal for customers and manufacturers continues to be preserving the quality of milk-based beverages made with date powder. In this study, the treatment of this beverage was studied using two methods: pulsed electric field treatment and thermal pasteurization at different powder ratios for a shelf life of 6 days. Moreover, the effects of the two treatments on the physical and microbiological properties of the beverage were studied. Positive and negative effects of the two treatments, powder ratios, and storage period on the beverage quality attributes were observed. The optimal condition for minimizing the microbial load and physical change of the beverage at the end of the shelf life was a pulse count of 80 for all of the powder ratios. Generally speaking, the PEF can be used to preserve the quality of milk–date powder beverages, allowing them to be stored for up to 6 days after processing them at 5 °C without noticeably losing their quality attributes.

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