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Influence of Ultrasound Pretreatment and Drying Techniques on Jute Leaves Drying and Quality Indices

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ABSTRACT

This study investigated the effects of ultrasound pretreatment and drying techniques on the drying process and quality of jute leaves. Fresh jute leaves, either pretreated with ultrasound or untreated, were dried in oscillatory and stationary modes. The impact on drying time, rehydration ratio, drying kinetics, and quality indices (protein, vitamins A and C, iron, and potassium) was assessed. Eight drying models were evaluated, with the Page model best fitting the experimental data. Ultrasound-pretreated leaves in oscillatory mode exhibited shorter drying times, while untreated leaves in stationary mode had a higher rehydration ratio. Nutrient composition varied, with protein ranging from 14.23% to 15.11%, vitamin A (2.31 to 3.02 mg/100g), vitamin C (26.18 to 32.09 mg/100g), iron (4.32 to 5.61 mg/100g), and potassium (185.36 to 210.24 mg/100g). Ultrasound pretreatment improved iron and vitamin C, while untreated leaves in oscillatory mode showed higher vitamin A, protein, and potassium. Conclusively, the combination of ultrasound pretreatment and oscillatory drying effectively enhanced drying efficiency and preserved key nutrients, making it a promising approach for optimizing the quality and processing of jute leaves.

Keywords: Jute leaves, Dryer, Drying Kinetics, Quality indices, Ultrasound Pretreatment

INTRODUCTION

Jute leaves (*Corchorus olitorius*) are erect woody leafy flowering plants that belongs to the family of *Tiliaceae*. Jute leaves are commonly grown in Thailand, Bangladesh, China, Nigeria and India among others (Islam and Ali, 2018). Nutritionally, jute leaves are a great source of vitamins (A, C and E), antioxidants, potassium, iron and micronutrients (Islam, 2013; Ali *et al*., 2020). The lifespan of jute leaves depends on various factors, such as the freshness of the leaves at the time of purchase, storage conditions, and the climate in which they were grown (Giro and Ferrante, 2018). Post-harvest losses, limited shelf life, transportation losses, and seasonal unavailability are challenges associated with jute leaves. These challenges have prompted the need to explore drying as a preservation method to address these issues.

Drying is one of the oldest methods for food preservation which involves removal of moisture in food using heat energy (Phalak and Banerhee, 2020). Drying is the process of lowering the water content of food by circulating heated air around them while controlling the temperature and humidity to a specific level to prevent physiological, microbial growth and enzymatic modifications (Rodríguez *et al*., 2018). Drying can be achieved with the application of a variety of techniques such as sun drying, infrared drying,

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freeze drying, microwave drying and conventional air drying. However, effective preservation methods, such as drying, can maintain their quality (Ghellam *et al*., 2022). According to Wu *et al*. (2020), the final quality of preserved products is significantly affected by ineffective drying techniques. Sanusi *et al.* (2023) reported that operational mode of dryer can affect the quality and energy consumption of rice.

Ultrasound is an innovative non-thermal technology capable of inducing mechanical, cavitation, and sponge effects on food substances (Bhargava *et al*., 2021). Ultrasound is a processing method that involves the use of acoustic waves with a frequency higher than 20 kHz that can cause physicochemical changes in food products (Bhargava *et al*., 2021; Sanusi *et al*., 2024a; Sanusi *et al*., 2024b). Ultrasound pretreatment improves drying characteristics by creating microchannels in the food tissue (Xu *et al*., 2021; Pandiselvam *et al*., 2023). This process helps internal moisture diffuse more easily in the final product and reduces barriers to water migration. Several research were conducted on the functional composition and drying kinetics of commonly utilized varieties of leafy vegetables as reported by Morakinyo *et al*. (2020); Lemus-Mondaca *et al*. (2021); Song *et al*. (2021) and Oladejo *et al*. (2023). However, literature is sparse on the effect of ultrasound pretreatment and drying techniques on jute leaves drying and quality indices. Therefore, examining the influence of ultrasound pretreatment and drying techniques could aid in selecting the appropriate drying technique and determining its impact on the quality indices of jute leaves. Therefore, this study aimed to determine the effect of ultrasound pretreatment and drying techniques on the drying and quality indices of jute leaves**.**

MATERIALS AND METHODS

Sample Collection

The jute leaves were taken off the stems and then carefully sorted to eliminate any damaged leaves or unwanted substances. The leaves were then washed to remove external contaminants like sand and allowed to drain. The jute leaves were then separated into two portions: the first portion was treated with ultrasound before drying, while the second portion was left untreated (control). Each portion was further divided into two portions. The ultrasound pretreatment was done using an Ultrasonic cleaner (CJ: 008, China) with a power of 50 W and a frequency of 40 kHz. 10 g of jute leaves was weighed and placed in 500 ml distilled water inside the Ultrasonic Cleaner for 30 mins. The drying process was monitored for four different samples using a fabricated oscillatory dryer, which operated in both stationary and oscillatory modes at a temperature of 60℃. These samples were identified as ultrasound-pretreated oscillatory dried jute leaves (UPOJL), ultrasound-pretreated stationary dried jute leaves (UPSJL), untreated oscillatory dried jute leaves (UNOJL), and untreated stationary dried jute leaves (UNSJL). The drying continued until a consistent weight was achieved for each sample.

Drying Kinetics

The initial weight loss in the dryer occurred after 10 min intervals and later at 2 min at consistent drying temperature until a stable weight was achieved. The tangent method was employed to construct the drying curve and drying rate curve, this approach entails plotting the experimental data of sample mass against time at a consistent drying temperature. According to Morakinyo *et al*. (2020), Equations 1, 2, and 3 were used to evaluate the drying rate, and moisture content of both wet basis and dry basis.

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$$D_r = \frac{C_{mc}\,(g)}{C_t\,(sec)} \quad [1]$$

$$\%MC_{wb} = \frac{W - W_s}{W} \times 100 \quad [2]$$

$$\%MC_{db} = \frac{W - W_s}{W_s} \times 100 \quad [3]$$

where D_r is the drying rate, C_{mc} is the change in moisture content, MC_{wb} is the moisture content in wet basis, MC_{db} is the moisture content in dry basis, C_t is the change in time, W is the weight of dried solid + moisture (g) and W_s is the weight of dried solid/ constant weight obtained (g). M_i

The moisture ratio (MR) of the jute leaves samples can be determined using Eq. (4), as described by Hussein *et al*. (2018).

$$MR = \frac{M - M_e}{M_i - M_e} = \exp(kt) \quad [4]$$

where MR is the moisture ratio, M is the moisture content at any time 't' (kg water/ kg dry matter) (% db), M_e is the equilibrium moisture content at the conditions of the drying air (kg water/ kg dry matter) (% db), Mi is the initial moisture content of sample (kg water/ kg dry matter) (% db), t is the drying time (min) and k is the drying constant (min^{-1}).

The drying curves were generated by plotting the graph of Moisture Ratio (MR) against time as obtained in the experimental data in Eq. (4).

Mathematical Modelling of Drying Curves

There are several mathematical methods available for predicting drying processes. Eight existing mathematical models were employed for this study (Table 1), including the Parabolic (2000), Henderson and Pabis (1974), Prakash and Kumar (2012), Page (1949), Newton (Lewis) (1921), Logarithmic (1971), Wang and Singh (1978), and Midilli (2002) models to determine the most suitable drying model that fits the drying curve.

Quality Indices

Rehydration

For each sample, 3 g of dried jute leaves was used, and water was brought to a temperature of 60°C. The weighed jute leaves samples were then immersed in the hot water and stirred to ensure thorough soaking. After soaking for 20 mins, the water was drained, and the leaves were gently blotted with tissue paper to remove surface water. Rehydration was done for each sample, and the Rehydration ratio was calculated in average values using Eq. (5) as described by Wang *et al*., (2019).

$$RR = \frac{W_r}{W_d} \quad [5]$$

where W_r is the weight of rehydrated sample and W_d is weight of the dehydrated vegetable sample.

Table 1: Mathematical Models

Model	Equation
Midili	$MR = a\,e^{-kt^n} + bt$
Page	$MR = e^{-kt^n}$
Logarithmic	$MR = a\,e^{-kt} + c$
Modified Page	$MR = e^{(-kt)^n}$
Henderson and Pabis	$MR = a\,e^{-kt}$
Modified Henderson and Pabis	$MR = a\,e^{-kt} + b\,e^{-gt} + c\,e^{-ht}$
Newton	$MR = e^{-kt}$
Two-term	$MR = a\,e^{-k_0 t} + b\,e^{-k_1 t}$

MR is the moisture ratio, t is the temperature, k, n, a, b, c, g, h are empirical constant in the drying models.

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Determination of Protein

The Kjeldahl technique was used to determine the protein content. The nitrogen value was converted to protein using a ratio of 5.5 (Yakoub *et al*., 2018).

Determination of Vitamin A and C

To determine β-carotene content, 1 gram of the sample was extracted with 5 mL of methanol for 2 hours in the dark at room temperature. The β-carotene layer was separated using hexane in a separating funnel, adjusted to 10 mL, and dried with sodium sulphonate. Absorbance was measured at 436 nm with hexane as the blank, and β-carotene content was calculated using Eq. [6]. Vitamin C content was quantified by titration with 2,6-dichlorophenolindophenol. For preparation, 5 grams of the sample were ground with acid-washed sand and 10% TCA, filtered, and washed with TCA to a total of 100 mL. This solution was titrated with indophenol until a pink color appeared, determining the vitamin C content.

$$\beta\left(\frac{\mu g}{100g}\right) = A\,(436\ nm) \times V \times D \times 100 \times \frac{100}{W \times Y} \quad [6]$$

where β is the beta carotene, A is the absorbance, V is the total volume of extract, D is dilution factor; W is sample weight and Y is percentage dry matter content of the sample.

Mineral Analysis

Mineral analysis for the iron and potassium was performed using the AOAC method (AOAC, 2012).

Statistical Analysis

The regression analysis of the drying rate was evaluated using Statistical Package for Social Science (SPSS) version 20.0. The coefficient of determination R^2, Root Mean Squared Error (RMSE) and reduced χ^2 is used to evaluate the goodness of fit.

RESULTS AND DISCUSSION

Drying Curve of Jute Leaves

Figure 1 depicts the drying curve of jute leaves under the influence of ultrasound pretreatment and drying techniques. Changes were observed in the moisture ratio and drying time (Figure 1). The drying time ranged from 90 min to 120 min depending on the drying technique and pretreatment method. Ultrasound-pretreated oscillatory dried jute leaves (UPOJL), ultrasound-pretreated stationary dried jute leaves (UPSJL), untreated-oscillatory dried jute leaves (UNOJL), and untreated-stationary dried jute leaves (UNSJL) varied in their drying time. The moisture content of jute leaves decreases exponentially over time. It was observed that UPOJL dried faster compared to UPSJL, UNSJL and UNOJL. This could be attributed to the combined effect of oscillatory techniques and ultrasound pretreatment used in drying the jute leaves. This result corroborates with the findings of Bhargava *et al*. (2021) and Sanusi *et al.* (2024c) who reported that the drying process of fruits and vegetables can be accelerated with the application of ultrasound thereby reducing the drying time and preserves the product quality by enhancement in the rate of heat transfer. The study shows that the use of an oscillatory drying technique increases the drying rate of jute leaves thereby reducing the drying time. The increase in the rate of drying maybe as a result of an increase in movement and circulation of air. This result corroborates with Akan and Özkan, (2020) findings, that the drying efficiency can be improved with an oscillatory dryer in an oscillatory mode thereby reducing the drying time compared to stationary. The study also shows that the combination of ultrasound pretreatment and oscillatory dryer in an oscillatory mode improves the drying efficiency of the jute leaves which leads to reduction in the drying

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time and enhancement of the drying rate. According to Romero and Yépez, (2014), ultrasound application combination with hot air drying has a significant effect on the drying rate without affecting the quality. Similar results was reported on raspberries (Kowalski *et al*., 2016).

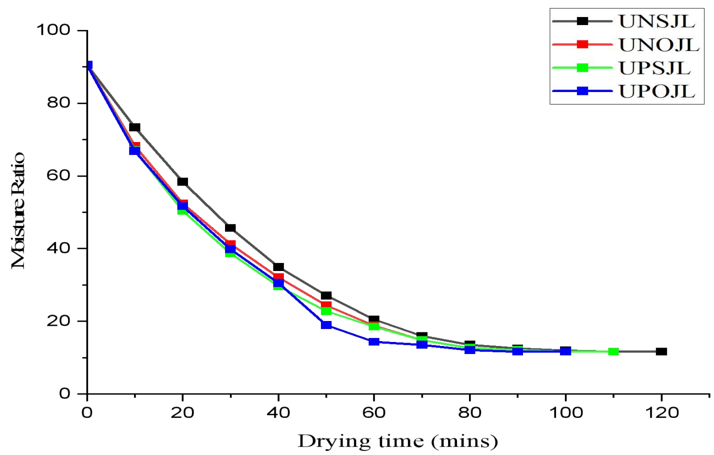

Figure 1: Drying curve of jute leaves dried in a stationary mode and in an oscillatory mode.

Modelling on Drying Characteristics of Jute Leaves

Table 2 illustrates the model parameters derived from the non-linear regression of the eight thin-layer drying models. The R^2 with the highest value and χ2 and RMSE with the lowest value were the basis of model selection for predicting the drying characteristics of the jute leaves (Hussein *et al*., 2018). It was observed that for UNSJL, UNOJL, UPSJL and UPOJL the page model was the most suitable model with the R^2, χ^2 and RMSE value of (1, 0.0000333 and 0.005545), (1, 0.0000236 and 0.00467), (1, 0.0000154 and 0.003769) and (1,0.0000199 and 0.004283) respectively. The R^2 value (1) derived from the page model is higher overall compared to the correlation coefficients obtained for other models, such as Logarithmic (0.996), Henderson and Pabis (0.988), Newton (0.988), Wang and Singh (0.512), Parabolic (0.723), Midilli (0.981), and Prakash and Kumar (0.887). Therefore, the Page model is the most suitable for the experimental dimensionless moisture content data for UNSJL, UNOJL, UPSJL and UPOJL with the Logarithmic model being the next favourable. However, considering the model with the overall lowest χ^2 and RMSE, Page model (χ^2= 0.0000154 and RMSE= 0.003769) is the most suitable for the dimensionless moisture content data followed by Logarithmic (χ^2= 0.000324 and RMSE= 0.017301), Henderson and Pabis (χ^2= 0.000867 and RMSE= 0.028293), Newton (χ^2= 0.000867 and RMSE= 0.028293), Prakash and Kumar (χ^2= 0.008389 and RMSE= 0.088), Parabolic (χ^2= 0.020604 and RMSE= 0.137908), Wang and Singh (χ^2= 0.038791 and RMSE= 0.189228) and Midilli (χ^2= 0.084886 and RMSE= 0.279922) models. The result shows that Page model was observed to satisfactorily describe the drying characteristics of jute leaves dried in an oscillatory dryer.

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Table 2: Estimated parameter and comparison criteria of moisture ratio of jute leaves

Models	Constant	Treatment method	R^2	Chi	RMSE
Page	k=0.326 n=0.586	UNSJL	1	0.0000333	0.005545
	k=0.478 n=0.498	UNOJL	1	0.0000236	0.00467
	k=0.511 n=0.486	UPSJL	1	0.0000154	0.003769
	k=0.494 n=0.499	UPOJL	1	0.0000199	0.004283
Logarithm	k=0.120 a=0.968 b=0.027	UNSJL	0.995	0.000407	0.019393
	k=0.148 a=0.968 b=0.029	UNOJL	0.995	0.000453	0.02046
	k=0.154 a=0.972 b=0.026	UPSJL	0.996	0.000324	0.017301
	k=0.156 a=0.969 b=0.028	UPOJL	0.995	0.000514	0.02179
Henderson and Pabis	a=0.990 K=0.108	UNSJL	0.988	0.001021	0.030707
	a=0.994 k=0.132	UNOJL	0.987	0.000962	0.029802
	a=0.995 k=0.139	UPSJL	0.988	0.000867	0.028293
	a=0.995 k=0.139	UPOJL	0.988	0.000887	0.028608
Newton	k=0.109	UNSJL	0.987	0.001013	0.030581
	k=0.133	UNOJL	0.987	0.000954	0.029672
	k=0.139	UPSJL	0.988	0.000867	0.028293
	k=0.139	UPOJL	0.988	0.000878	0.028473
Wang and Singh	k=-0.029 c=0.000	UNSJL	0.472	0.038791	0.189228
	k=-0.032 c=0.000	UNOJL	0.446	0.053094	0.221382
	k=-0.030 c=0.000	UPSJL	0.342	0.048634	0.21188
	k=-0.035 c=0.000	UPOJL	0.512	0.087171	0.283664
Parabolic	k=-0.019 c=0.000 a=0.661	UNSJL	0.723	0.020604	0.137908
	k=-0.020 c=0.000 a=0.657	UNOJL	0.695	0.027111	0.158196
	k=-0.018 c=0.000 a=0.622	UPSJL	0.658	0.025133	0.152314
	k=-0.023 c=0.000 a=0.683	UPOJL	0.716	0.042144	0.197237
Midilli	k=0.242 b=-0.002 a=0.273 n=3.329x10^{-8}	UNSJL	0.961	0.086277	0.282206
	k=0.285 b=-0.002 a=0.220 n=4.231x10^{-8}	UNOJL	0.981	0.084886	0.279922
	k=0.287 b=-0.002 a=0.209 n=3.374x10^{-9}	UPSJL	0.979	0.084888	0.279925
	k=0.226 b=-0.002 a=0.192 n=-2.883x10^{-8}	UPOJL	0.661	0.084906	0.279955
Prakash and Kumar	a=-2.655x10^{-6} b=0.001 c=-0.041 d=0.836	UNSJL	0.887	0.008389	0.088
	a=-3.584x10^{-6} b=0.001 c=-0.044 d=0.835	UNOJL	0.868	0.014208	0.114521
	a=-2.805x10^{-6} b=0.001 c=-0.041 d=0.807	UPSJL	0.843	0.011148	0.101441
	a=-4.788x10^{-6}b=0.001 c=-0.051 d=0.855	UPOJL	0.882	0.044707	0.203146

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Influence of Ultrasound Pretreatment and Drying Techniques on the Rehydration Ratio of Dried Jute Leaves

The rehydration ratio of a substance quantifies the ability of a substance to reabsorb water and return to its original hydrated state. The influence of ultrasound pretreatment and drying techniques on the rehydration ratio of dried jute leaves ranged between 3.93 and 5.3. The rehydration ratio for the samples were UPOJL (3.93), UPSJL (4.27), UNOJL (4.4), and UNSJL (5.3). The variation in the rehydration ratio can be explained by the disruption of cell structures and the release of soluble components during the ultrasound treatment, which in turn reduces the sample's ability to hold water. This finding aligns with the results reported by Sunil *et al*. (2017), who observed that ultrasound pretreatment of dried samples led to a lower rehydration ratio, possibly due to the adverse effects of ultrasound.

Influence of Ultrasound Pretreatment and Drying Techniques on the nutritional composition of Dried Jute Leaves

Figure 2a shows the influence of ultrasound pretreatment and drying techniques on the crude protein content of dried jute leaves. The crude protein content of the dried jute leaves ranged between 14.23% and 15.11%. It was observed that the untreated samples UNOJL jute leaves and UNSJL jute leaves have the highest crude protein compared to ultrasound-pretreated samples UPOJL and UPSJL. This may be a result of influence of ultrasound treatment on the physicochemical and functional properties of the proteins. This result corroborates with the findings of Rodríguez *et al*. (2018), who reported that the use of ultrasound either as a pretreatment or during the drying process resulted in significant reduction of it due to denaturation of the enzyme protein.

The influence of ultrasound pretreatment and drying techniques on the vitamin A and C content of dried jute leaves is depicted in Figure 2b. The vitamin A content of the dried jute leaves ranged from 2.31 mg/100g to 3.02 mg/100g. A higher vitamin A content was observed in UNOJL compared to that of UPOJL, UPSJL and UNSJL. This may be as a result of cavitation bubbles, which occur during ultrasound pretreatment, that might lead to vitamin A degradation. This result aligns with the findings of Frias *et al*. (2010), that the ultrasound effect on the treatment of vegetables such as creation of microscopic channels, micro-agitation and cavitation of water molecules can further lead to vitamin A degradation. The vitamin C content of the dried jute leaves ranged between 26.18 mg/100g and 32.09 mg/100g. It was also observed that the vitamin C content of UPOJL was slightly higher than UNOJL but significantly greater than UPSJL and UNSJL. The slight increase in vitamin C content of UPOJL compared to UNOJL may be attributed to the ultrasound effect on the jute leaves during the drying process. Similar results were reported by Cao et al. (2020), indicating that ultrasound application before drying can lead to a shorter drying time and better retention of important compounds, such as Vitamin C. The significant increase in the vitamin C content of UPOJL and UNOJL compared to UNSJL and UPSJL may be attributed to the drying characteristics and oscillatory temperature. This result corroborates with Akan and Özkan (2020) findings that the drying efficiency can be improved with an oscillatory dryer in an oscillatory mode thereby reducing the drying time compared to oscillatory dryer in a stationary mode leading to retention in the nutritional quality such as vitamin C. The oscillatory mode of the oscillatory dryer also has impact on the vitamin content.

Figure 2c shows the Influence of ultrasound pretreatment and drying techniques on the mineral content of jute leaves. The iron

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content of the dried jute leaves ranged from 4.32 mg/100g to 5.61 mg/100g. It was observed that the iron content of UPOJL jute leaves was slightly higher than that of UNOJL jute leaves, UPSJL jute leaves and UNSJL jute leaves. This may be as a result of the effect of ultrasound on the nutritional and drying mechanism used during drying. The result contradicts the findings of Kumar *et al*. (2023), that when ultrasound pretreatment is applied under identical drying conditions, decreases the overall mineral content of the samples in comparison to the untreated samples. The potassium content of the potassium ranged between 185.36 mg/100g and 210.24 mg/100g. A significant increase in the potassium content of UNOJL was also observed compared to other drying techniques UPOJL, UPSJL and UNSJL. The increase in potassium of UNOJL may be attributed to the difference in the effect of ultrasound pretreatment on the quality properties of the leaves. This result contradicts the findings of Rawson *et al*. (2011), that ultrasound as a pretreatment method enhances the drying time thereby increasing the retention of bioactive compounds such as potassium. Also sample dried in an oscillatory dryer such as UPOJL and UNOJL has higher potassium content compared to UPSJL and UNSJL.

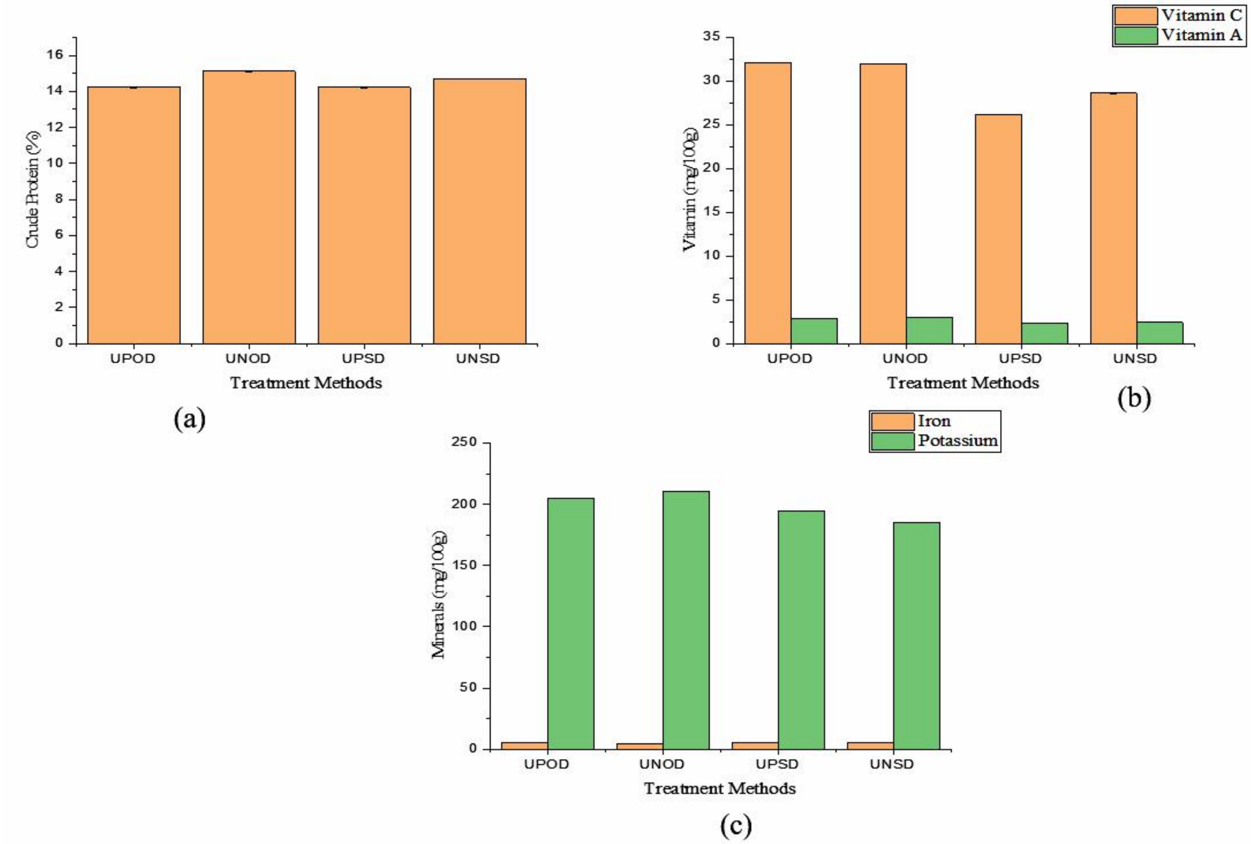

Figure 2: Influence of ultrasound pretreatment and drying techniques on the (a) crude protein (b) vitamins (c) minerals of dried jute leaves. The superscripts with different letter on the column graph indicate statistical difference at 95% confidence level.

CONCLUSION

The study assessed the effect of ultrasound pretreatment and drying techniques on the drying time, drying kinetics, rehydration ratio, protein, vitamin A, vitamin C, iron, and potassium of dried jute leaves. The study

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identified that ultrasound-pretreated jute leaves in oscillatory mode dried faster compared to other drying techniques. The drying process progressed through a decreasing rate period until a constant rate was attained. The experimental data were modelled using eight drying models and page model was found to be the most suitable, with an overall R^2, χ^2, and RMSE values of 1, 0.0000154, and 0.003769, respectively. Untreated dried jute leaves in oscillatory mode favours vitamin A, protein and potassium while ultrasound pretreated jute dried leaves in oscillatory mode favours iron and vitamin C contents. Moreover, untreated jute leaves in stationary mode exhibited the highest rehydration ratio. This study highlights that ultrasound pretreatment accelerates the drying of jute leaves, with the page model offering the best fit for the data. It underscores differing quality results between pretreated and untreated jute leaves.

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