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Modelling of Moisture Release Dynamics During the Drying Process

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Abstract: The aim of this paper was to determine the dynamics of lettuce (*Lactuca sativa* L.) drying at different temperatures and to establish mathematical models that describe these dynamics. Oven drying was carried out at 80 °C and 105 °C, and the mathematical dependencies tested included different polynomial and exponential functions. Experiments confirmed that the fifth-order polynomial mathematically describes best the time dependence of moisture loss from the lettuce leaves at both 80 °C and 105 °C, both for the control samples and for the samples treated with different amounts of plasma activated water. However, it is not possible to determine the undoubted influence of PAW on the dynamics of moisture loss from lettuce leaves.

Keywords: drying kinetics; lettuce; moisture release; plasma activated water

1 INTRODUCTION

It is world-wide known that the lettuce (*Lactuca sativa* L.) is one of the most important vegetables in nutritional sense. Also, the lettuce is a very demanded crop in different markets [1, 2]. Every lettuce producer tries to achieve higher yields with better quality of crops. In terms of current climate challenges production of lettuce should be aligned with decrease in use of mineral fertilizers and chemicals in general.

It is also well known that the drying presents one of the most efficient processes for any bio-product as it synchronizes both heat and mass transfer. Drying, in which the water content and activity are decreased, is an important method of preservation and production of a wide variety of products. It is documented that mechanical drying methods, like oven drying or fluidized bed drying, as well as different microwave drying methods, can provide an enhanced product in terms of more consistent quality, while taking less time and simultaneously minimizing crop losses [3]. In biotechnology, the production of active dry yeast (ADY) has significantly reduced the cost of yeast transport and storage, prolonged shelf life, and simplified the handling of yeasts crucial to the baking, wine, and brewing industries. Spray drying, spouted bed drying, and fluidized bed drying are some of the methods used for ADY production [4]. Various drying methods are used in research on the loss of volatile substances from medical herbs and vegetables [5, 6]. Roknul et al. [7] found that hot-air-assisted radio frequency drying dries finely chopped lettuce the fastest and ensures uniform drying and quality of the dried samples. These methods could improve the current degree of affirmation of different dehydrated foods in the global market [8]. Efficient and economical use of energy in drying methods is also a hot topic in new research considering current climate and energy crises [9].

According to FAO, post-harvest loss in vegetables is approximately 30-40% mostly due to inappropriate post-harvest handling, as well as lack of infrastructure, marketing, processing and storage facilities [10]. As a consequence, the food processing industry can play a pivotal role in reducing these post-harvest losses which will ensure better earnings for the growers [11]. For example, to upgrade the quality of dried chili, authors introduced some mechanical, solar, and oven dryers in order to decrease the drying time [12]. The physical properties of food, such as texture, shape, shrinkage, etc., which have a significant impact on the end consumer, are altered by drying, which has already been researched [13, 14]. This can be partially influenced by processes such as steam or chemical blanching, ultrasonic blanching, coating, etc. [15]. In the production of ADY, the viability and genome stability of yeast after dehydration and rehydration are crucial for its effective use in the food industry. Various studies have examined factors that affect viability during the drying process, including minimum survivable moisture levels, yeast growth medium, yeast cell phase, and drying method [16, 17].

The drying rate is affected by several factors, such as air temperature but also the shape and velocity of the investigated material [18]. Other authors report that the drying of food products like fruits and vegetables is vastly affected by several following factors: drying temperature, drying time, relative air humidity, air flow rate (or velocity), size (material thickness), surface area, volume and pressure [19]. It has been found that the increased temperatures result in decreased drying time and rise in the effective moisture diffusivity [20].

The investigation of drying behavior of many materials has been a subject of interest for a large number of researchers from both theoretical and practical point of view. During the studies conducted concerning the drying behavior of different agricultural products, many algebraic models were used to describe the complex process of drying. The thin-layer drying models are the most often. The equations for the thin-layer drying are used to estimate drying time of many products but also to generalize drying curves as well. Several researchers have proposed appropriate mathematical models for the thin layer drying in case of many agricultural products [21]. Mathematical models of the drying process are also used for designing new or improving existing drying systems and controlling the drying process [11].

The use of plasma activated water (PAW) in the agricultural and food industry has provided more and more insights in recent years. To our best knowledge, the influence of PAW on drying kinetics has not yet been investigated in the scientific literature. Currently, the scientific community is interested in plants treated with PAW, which can be used as a disinfectant, fertilizer or growth stimulator. The presence of nitrate and nitrite ions could be responsible for improved plant growth [22]. Studies on various vegetable crops have already demonstrated the influence of PAW on the growth and production of peppers and lettuce [23, 24]. The drying of such and similar vegetable or fruit crops grown under the influence of PAW can open up new perspectives for the agricultural and food industry's responses to the current climate changes in the world. The aim of this research was to determine the dynamics of lettuce (*Lactuca sativa* L.) drying at different temperatures and to establish mathematical models that describe these dynamics.

2 MATERIALS AND METHODS

The experiment was conducted with a two-factorial experiment; PAW treatment for lettuce seeds and drying temperature, in three replicates.

2.1 Preparation of Plasma Activated Water

Preparation of Plasma Activated Water (PAW) -active species are generated in a plasma reactor formed by a single electrode atmospheric pressure plasma jet. This atmospheric pressure plasma jet is made of a quartz tube with 1,5 mm outer and 1 mm inner diameter, and a copper (Cu) wire with a 100 μm diameter that is inserted into a capillary and represents an electrode. The electrode is powered with a sinusoidal voltage 28 kHz waveform with a 12 kV maximum voltage (PVM500-2500 Plasma Power Generator, Information Unlimited). This electrode was selected based on previous extensive optimization work [25].

The delivered power is usually about 15 W. The discharge is generated in nitrogen gas (purity of 99,996%), supplied to the capillary at a 500 sccm flow rate. Constant volume of the sample (800 mL) in the Berzelius beaker is brought into contact with the plasma jet by placing the liquid at a distance of 5 mm from the capillary opening, which gains the comparable production of H_2O_2 and NO_2^- in the PAW. Commercial purified water of pharmaceutical grade (Pharmacopoeia Europaea, Ph. Eur. 9) with a pH of 6,5 and a conductivity of 0,98 μS/cm was used.

The treatment time with the nitrogen plasma jet was 70 min. The plasma activated samples are analyzed immediately after treatment, but also several times during their storage. The concentration of NO_2^-, NO_3^- and H_2O_2, as well as the pH of the samples are determined with QUANTOFIX test strips. The strips are assessed by using the QUANTOFIX Relax unit optical reader (from MachereyNagel, GmbH, Düren, Germany), which permits quantitative analysis with high accuracy. The nitrate/nitrite strips were calibrated with $NaNO_2$ and NH_4NO_3 solutions of known concentrations, and the calibration was checked with UV–VIS absorption spectroscopy measurements.

It is known that the ageing dynamics of PAW depends on the acidity (pH), which was controlled by adding metal ions to the water [26, 27]. The magnesium (Mg) ions were added by inserting a solid piece of Mg (5 g) immediately during the plasma treatment. It was left in that liquid for an hour after the treatment. Below are the values measured after treatment, which correspond to the values at the time of water use: pH 6 ± 0,2, H_2O_2 4,4 ± 0,2 mg · L^{-1}, NO_2^- 5,5 ± 1 mg · L^{-1}, NO_3^- 20 ± 2 mg · L^{-1}.

It was found that the concentration of PAW used in this study ensures the stability of nitrogen ions in the concentration. The preparation of PAW water was carried out under controlled laboratory conditions and it was necessary to ensure a stable concentration that would remain unchanged until the time of use in the experiment.

2.2 Set up of the Experiment

The experiment consists of three replicates of each variable (control and two treatments with PAW) and was set up on December 12th, 2023 at the location of Slobodnica (45°9'58" N, 17°57'8" E, an elevation of 87 m, Slavonia, eastern part of Croatia) in the greenhouse of the Biotechnical Department of the University of Slavonski Brod. Lettuce variety Flambine (Lot: P03953, Vilmorin S.A., France) was obtained from a commercial lettuce company. The PAW was prepared at the Institute of Physics (Zagreb, Croatia) and delivered to Slavonski Brod the day before watering the plants.

Figure 1 Lettuce at different growth stages

The lettuce seeds were sown in modular trays (Fig. 1, PöpellmannTEKU (BP3153/60), dimensions 53 × 31 × 5.6 cm) equipped with 60 sowing sites (with volume of each site 76 mL) filled with cultivation medium Potgrond P (Klasmann-Deilmann). Authors optimized greenhouse conditions to maximize seedling growth. Pre-germination temperature was 15 °C and a post-germination temperature was 10 °C-12 °C during the day and 6 °C-10 °C during the night. After the seedlings made it to the required growth stage (4-5 leaves) they were hardened off and then planted in 3,75 L pots filled with the mixture of soil and cultivation medium ECO (Klasmann-Deilmann) with the following physical and chemical properties: pH in H_2O 6,8, pH in KCl 6,42, P_2O_5 23,57 mg /100 g of soil, K_2O 23,09 mg /100 g of soil, 12,1 % of humus and 9,6% of $CaCO_3$, powdery clay loam, physiologically active moisture of 26,7 % of mass and 1,24 dS/m of electrical conductivity. The mixture was analyzed at the Faculty of Agriculture, University of Zagreb and Regional Center for Biotechnological Research, Slavonski Brod.

The plants were watered three times with PAW, out of a total of ten waterings until the end of the experiment on March 20th, 2024. The remaining waterings were carried out with the well water from the specified location in Slobodnica. In the first treatment with PAW water (PAW1), the lettuce was watered three times during the growing period with 1,5 dL of PAW water each time, while in the second treatment (PAW2), 3 dL of PAW water was used. The control plants were watered only with well water. The treatment times are based on the expected behavior of the plants in terms of nutrient uptake at certain growth stages and under certain growth conditions to ensure the safe uptake of nitrogen ions in the plant while ensuring stable yields. PAW is not yet easily home produced so the mixed model could be appropriate for the beginning of practical applications.

2.3 Drying Process

For the purpose of drying experiments two largest leaves from each lettuce head (Figure 1) were taken and cut to three pieces by the knife. All those pieces were placed together in a container and put in oven dryer (Memmert Celsius) already set up and stabilized at 105 °C. The next two largest leaves were taken and cut to three pieces and dried by the same methodology at 80 °C. Initial mass and mass at each temperature (30-minutes interval for 105 °C and 20-minutes interval for 80 °C) were measured using an analytical balance with accuracy of 0,01 g (PL3002, Mettler-Toledo International Inc., Greifensee, Switzerland). The drying process was stopped after several measurements had approximately the same values which indicated the end of moisture release.

2.4 Mathematical Modelling of Drying Kinetics

The mean values of three individually measured masses (replicates) were mathematically converted into relative percentages in relation to the initial mass of the sample. By simulating the data obtained in this way, an attempt was made to find a mathematical model that best describes the observed regularity of moisture loss. The obtained research data were mathematically processed using the Origin 2024b computer program [28].

Exponential and polynomial expressions were reported in several papers that investigated drying models and used computer simulations to mathematically describe certain dynamic processes [29, 30]. Based on those findings this analysis started from simpler mathematical expressions. The simulations carried out included the non-linear polynomial fittings of orders 2 to 5 as well as the exponential decay. Following equations describe these mathematical models: second order (1), third order (2), fourth order (3) fifth order (4) and exponential decay (5).

$$y = A_0 + A_1 \times x + A_2 \times x^2 \quad (1)$$

$$y = A_0 + A_1 \times x + A_2 \times x^2 + A_3 \times x^3 \quad (2)$$

$$y = A_0 + A_1 \times x + A_2 \times x^2 + A_3 \times x^3 + A_4 \times x^4 \quad (3)$$

$$y = A_0 + A_1 \times x + A_2 \times x^2 + A_3 \times x^3 + A_4 \times x^4 + A_5 \times x^5 \quad (4)$$

$$y = y_0 + A_1 e^{(-x/t_1)} \quad (5)$$

R^2 parameter was used to determine how well the regression model fits the real data and ANOVA was used for statistical processing of the data, using the F-value to assess the acceptability of a particular model. Chi-square parameter was used to evaluate the difference between the observed and expected values.

3 RESULTS

In this work, experiments were carried out to determine the dynamics of moisture release from lettuce leaves. In addition, the possible influence of PAW on these processes was also investigated. The results obtained were simulated with different mathematical models. Only the three best simulations for PAW1, PAW2 and control samples are presented in this paper.

3.1 Control

Drying of lettuce leaves at 105 °C and 80 °C was carried out for the control samples and for PAW1 and PAW2 samples. The results obtained and recalculated to relative mass for the control samples are shown in Fig. 2.

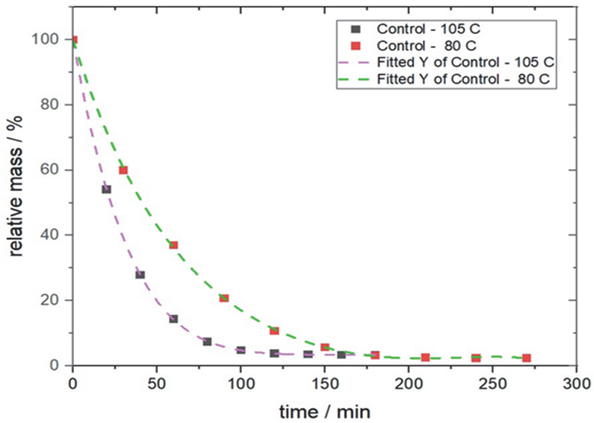

Figure 2 Moisture release dynamics for control samples of lettuce leaves at 105 °C and 80 °C and the fitting with polynomial functions of 5th order

The experimental data obtained at 105 °C were simulated with several possible curves. A comparison of the three best simulations is shown in Tab. 1.

From the data presented, it is clear that the fifth-order polynomial has the highest values of R^2 and F, and the lowest reduced χ^2 which makes it the best model describing the experimental data obtained. The visual appearance of the mentioned simulation is shown in Fig. 2.

Table 1 Comparison of simulations of different mathematical models for control samples at 105 ºC

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99989	0,19220	11824,44
Polynomial of 5th order	0,99999	0,02757	65961,29
Exponential decay	0,99906	1,22254	3714,83

A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of control samples at 105 ºC is given in Tab. 2.

Table 2 Values of the coefficients of the fifth-order polynomial obtained by simulations of control samples at 105 °C

Coefficient	Value	Standard Error
A0	99,98697	0,16463
A1	–2,94114	0,02281
A2	0,03671	9,03365E^{-4}
A3	–2,34931E^{-4}	1,34522E^{-5}
A4	7,70149E^{-7}	8,39896E^{-8}
A5	–1,03205E^{-9}	1,85777E^{-10}

The experimental data obtained at 80 °C were also simulated with several possible curves. A comparison of the three best simulations is shown in Tab. 3.

Table 3 Comparison of simulations of different mathematical models for control samples at 80 °C

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99962	0,72317	3315,89
Polynomial of 5th order	0,99990	0,47837	4010,96
Exponential decay	0,99863	1,88027	2548,12

It is also clear that the fifth-order polynomial has the highest values of R^2 and F and the lowest reduced χ^2 values for the data obtained at 80 ºC, which makes it the best model describing the experimental data at lower temperature, too. The visual appearance of the mentioned simulation is shown in Fig. 2. A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of control samples at 80 ºC is given in Tab. 4.

Table 4 Values of the coefficients of the fifth-order polynomial obtained by simulations of control samples at 80 ºC

Coefficient	Value	Standard Error
A0	99,8252	0,68581
A1	–1,6285	0,06334
A2	0,01234	0,00167
A3	–5,74257E^{-5}	1,66039E^{-5}
A4	1,59701E^{-7}	6,91118E^{-8}
A5	–1,92255E^{-10}	1,01912E^{-10}

3.2 PAW1

The results obtained from drying of lettuce leaves at two temperatures and recalculated to relative mass for the PAW1 samples are shown in Fig. 3.

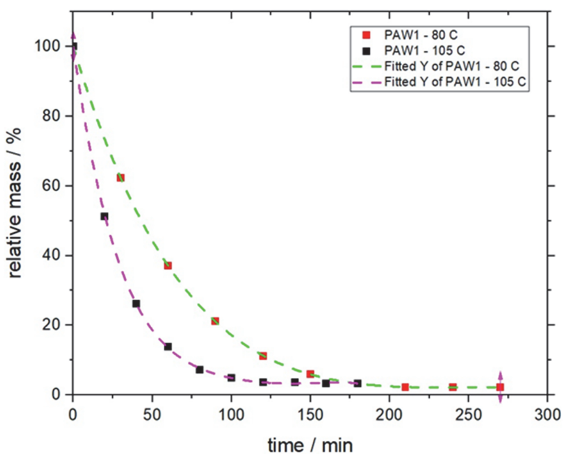

Figure 3 Moisture release dynamics for PAW1 samples of lettuce leaves at 105 °C and 80 °C and the fitting with polynomial functions of 5th order

The experimental data obtained for the lettuce drying at 105 °C were carefully simulated with several possible curves. A comparison of the three best simulations is shown in Tab. 5.

Table 5 Comparison of simulations of different mathematical models for PAW1 samples at 105 °C

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99946	0,95448	2331,34
Polynomial of 5th order	0,99994	0,12346	14426,29
Exponential decay	0,99971	0,42375	7003,45

From the data obtained for PAW1 samples, it is clear that the fifth-order polynomial has the highest values of R^2 and F and the lowest reduced χ^2 values which makes it the best model describing the experimental data. The visual appearances of the mentioned simulations are shown in Fig. 3. A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of PAW1 samples at 105 ºC is given in Tab. 6.

Table 6 Values of the coefficients of the fifth-order polynomial obtained by simulations of PAWI samples at 105 °C

Coefficient	Value	Standard Error
A0	99,93038	0,3484
A1	–3,22359	0,04827
A2	0,04656	0,00191
A3	–3,5818E^{-4}	2,84684E^{-5}
A4	1,43002E^{-6}	1,77744E^{-7}
A5	–2,31448E^{-9}	3,93153E^{-10}

Analogous to the above, the experimental data obtained at 80 °C were also simulated with several possible curves. A comparison of the three best simulations is shown in Tab. 7.

The fifth-order polynomial has the highest values of R^2 and F factor and the lowest reduced χ^2 values for the data obtained at 80 ºC, too. It makes it also the best model describing the experimental data at 80 ºC. The visual appearances of the mentioned simulations are also shown in Fig. 3. A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of PAW1 samples at 80 ºC is given in Tab. 8.

Table 7 Comparison of simulations of different mathematical models for PAW1 samples at 80 °C

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99999	0,02333	104489,79
Polynomial of 5th order	1	0,00755	258386,05
Exponential decay	0,99853	2,38226	1362,68

Table 8 Values of the coefficients of the fifth-order polynomial obtained by simulations of PAW1 samples at 80 ºC

Coefficient	Value	Standard Error
A0	100,00132	0,08615
A1	–1,5159	0,00796
A2	0,00943	2,10108E–4
A3	–3,0453E–5	2,08584E–6
A4	5,37752E–8	8,68205E–9
A5	–4,33307E–11	1,28026E–11

3.3 PAW2

The drying of lettuce leaves at two temperatures resulted in two sets of data. Experimental data obtained and then recalculated to relative mass for the PAW2 samples are shown in Fig. 4.

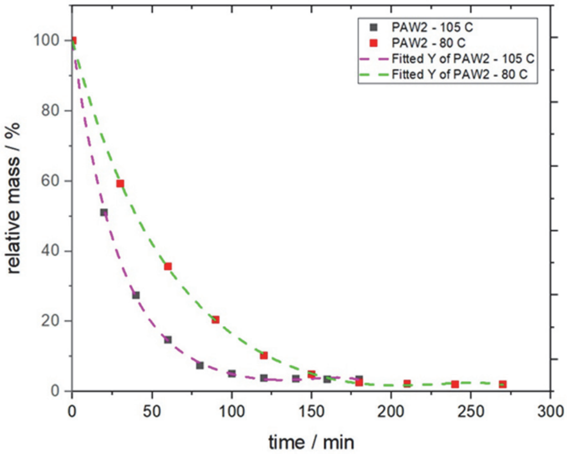

Figure 4 Moisture release dynamics for PAW2 samples of lettuce leaves at 105 °C and 80 °C and the fitting with polynomial functions of 5th order

As previously mentioned, the experimental data obtained at 105 °C were simulated with several possible curves. A comparison of the three best simulations is shown in Tab. 9.

Table 9 Comparison of simulations of different mathematical models for PAW2 samples at 105 ºC

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99902	1,74708	1267,81
Polynomial of 5th order	0,99977	0,51248	3460,25
Exponential decay	0,99964	0,52695	5608,03

From the data obtained for PAW2 samples, it is very clear that the fifth-order polynomial has the highest values of R^2 and the lowest reduced χ^2 value while F value is a little bit smaller than for exponential decay. The visual appearance of the polynomial fifth-order simulation is shown in Fig. 4. A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of PAW2 samples at 105 ºC is given in Tab. 10.

Table 10 Values of the coefficients of the fifth-order polynomial obtained by simulations of PAW2 samples at 105 °C

Coefficient	Value	Standard Error
A0	99,82968	0,70984
A1	−3,22211	0,09835
A2	0,04809	0,0039
A3	$-3{,}92083\text{E}^{-4}$	$5{,}80018\text{E}^{-5}$
A4	$1{,}67543\text{E}^{-6}$	$3{,}62138\text{E}^{-7}$
A5	$-2{,}89314\text{E}^{-9}$	$8{,}01015\text{E}^{-10}$

The experimental data obtained at 80 °C were also simulated with several possible curves. A comparison of R^2 parameter, F value and reduced χ^2 value for the three best simulations is shown in Tab. 11.

Table 11 Comparison of simulations of different mathematical models for PAW2 samples at 80 °C

Mathematical model	R^2	χ^2	F-value
Polynomial of 4th order	0,99957	0,81865	2937,66
Polynomial of 5th order	0,99988	0,28442	6766,48
Exponential decay	0,99879	1,94827	1644,54

Results show that the fifth-order polynomial has the highest values of R^2 and F and the lowest reduced χ^2 values for the data obtained at 80 ºC. It makes it also the best model describing the experimental data. The visual appearances of the mentioned simulations are also shown in Fig. 4. A detailed presentation of the coefficients of the fifth-order polynomial (Eq. 4) obtained by simulations of PAW2 samples at 80 ºC is given in Tab. 12.

Table 12 Values of the coefficients of the fifth-order polynomial obtained by simulations of PAW2 samples at 80 °C

Coefficient	Value	Standard Error
A0	99,87177	0,52882
A1	−1,69428	0,04884
A2	0,01377	0,00129
A3	$-6{,}96699\text{E}^{-5}$	$1{,}2803\text{E}^{-5}$
A4	$2{,}0514\text{E}^{-7}$	$5{,}32907\text{E}^{-8}$
A5	$-2{,}53318\text{E}^{-10}$	$7{,}85826\text{E}^{-11}$

Polynomial functions have variable terms (at least one) and possibly a constant term. In this case, the constant term of the polynomial expression is the largest and is always positive while the leading coefficient is the smallest one and it is always negative. For a fifth-degree polynomial (quintic equation) with a negative leading coefficient, the left end of the function increases as x decreases, while the right end of the function decreases as the value of the variable x increases [31]. The obtained experimental data shown in Figs. 2 to 4 confirm this theoretical model.

4 DISCUSSION

The use of PAW in agriculture is a relatively new concept whose application has increased significantly in recent years. This opens up great opportunities for various types of research, but also partially limits the possibilities of a well-founded comparison with other, similar research. Many previous studies have shown a positive correlation between the use of PAW and plant development, while for others a direct effect could not be proven [23, 24, 32]. The use of PAW in agriculture has been mostly associated with the treatment of seeds to stimulate germination [23,24] and as an alternative method in food technology to reduce contamination by microorganisms in the production of fresh or dried fruits and vegetables [33, 34], while only a few studies investigated the effects of PAW as a fertilizer by soil or foliar application on crop yield and dry matter [35, 36].

The aim of these studies was to determine the dynamics of moisture release from lettuce leaves at different drying temperatures (at 105 ºC and 80 ºC). In addition, the possible influence of PAW on these dynamics was observed as the lettuce plants were irrigated with PAW in two ways during growth and development. The control samples showed different drying dynamics at 105 ºC and 80 ºC, which was expected and consistent with previous results [11]. For Red Pepper (*Capsicum annum* L.) minimum time taken for safe moisture content (480 min) was obtained in oven drying at 70 ºC followed by drying at 65 ºC (540 min). Maximum time required to reach safe moisture content in sun drying method (1260 min) was followed by solar drying (900 min) [3]. Drying at 105 ºC accelerated the loss of moisture and brought the system to a constant mass earlier (Fig. 2). With the help of computer simulations, an attempt was made to find a mathematical model that best describes the experimentally determined dependencies. From the series of polynomial functions used and the exponential decay, the fifth-order polynomial proved to be the statistically best (R^2 = 0,99999, F = 65961,29, χ^2 = 0,02757 at 105 ºC and R^2 = 0,99990, F = 4010,96, χ^2 = 0,47837 at 80 ºC). Its agreement with the experimental data and the appropriateness of the chosen model, expressed by the parameters R^2, χ^2 and F values, are definitely the best of all tested functions. The fourth-order polynomial and the exponential decay are not far behind for R^2, but for the χ^2 and F values, especially for 105 ºC, this difference is very significant. The suitability of mentioned parameters has already been established in several papers [30, 37]. Mezguita et al. tried 15 different exponential models and the best one had R^2 = 0,9989 which is below values obtained in this paper.

The PAW1 and PAW2 samples were also subject to an identical drying treatment and computer simulation. As expected, drying at 105 ºC accelerated the loss of moisture and brought the system to a constant mass earlier than at 80ºC. The fifth-order polynomial proved to be the best mathematical model (R^2 = 0,99994, F = 14426,29, χ^2 = 0,12346 at 105 ºC and R^2 = 1, F = 258386,05, χ^2 = 0,00755 at 80 ºC) of all those used for PAW 1 samples. The value R^2 = 1 for the case of lettuce drying at 80 ºC, which represents a perfectly performed simulation, should be emphasized. Similar to the control samples, the fourth-order polynomial and the exponential decay at R^2 are not excessively lagging, but for the F-values the difference is significant at both temperatures. The results obtained for the PAW2 samples are largely similar to the results obtained for the PAW1 samples. The fifth order polynomial has the highest R^2 and F value from the ANOVA while the lowest χ^2 value at 80 ºC, while at 105 ºC the R^2 value is higher for the mentioned polynomial, but the F value is slightly higher for the exponential decay than for the fifth order polynomial. However, considering all the results, the claim that the fifth-order polynomial mathematically best describes the experimentally determined time dependence of mass loss is undoubtedly true, and the visual confirmation is shown in Fig. 4. When comparing the results of the samples irrigated with PAW with those of the control samples, no clear influence of PAW on the drying dynamics of lettuce leaves can be determined, i.e. the dependence of these dynamics on the amount of PAW used for irrigation is not clear.

Although the 5th degree polynomial was the best solution in all cases examined, the 4th degree polynomial was not far behind either (for example, R^2 for control at 105 ºC was 0,99999 for 5th degree polynomial compared to 0,99989 for 4th degree polynomial). On the other hand, the interpretation of the results with regard to their potential applicability is complicated by the fact that most fifth-degree polynomials are difficult to solve algebraically (according to Abel-Ruffini theorem) [38, 39].

Drying processes that demand more complex design, such as the production of active dry yeast, could use models that rely more on the physical properties of the dried material [40]. For optimal viability of yeast cells post-dehydration, cell growth conditions play vital role, as G1 phase cells show the highest dehydration resistance, similar to stationary phase cells, possibly owing to the accumulation of trehalose and dehydration-related proteins [41, 42].

The impossibility of drawing a conclusion about the influence of PAW on the drying effect is an incentive for new experiments in this area, both with different properties of PAW and with different vegetable or fruit crops. Given the lack of published research in this area, the authors are planning further studies on other agricultural crops to clarify the possible effects of PAW in the wider context of agricultural production and the food industry.

5 CONCLUSION

The results of the research conducted provide insight into mathematical models suitable for describing the dynamics of moisture release from lettuce leaves. As expected, the systems reached constant masses faster at 105 °C than at 80 °C in all cases studied. Specific statistical parameters were determined using computer simulations, from which it is clear that the fifth-order polynomial best mathematically describes the time dependence of moisture loss from the lettuce leaves at both 80 °C and 105 °C, both for the control samples and for the samples treated with different amounts of PAW (PAW1 and PAW2).

On the basis of the studies described, it is not possible to determine the undoubted influence of PAW on the dynamics of moisture loss from lettuce leaves, but these results provide a valuable insight into the research of possible applications of PAW in agriculture and the food industry in general. The potential of PAW in the agricultural and food industry could be great due to its practicality and versatility. The production of this type of water is simple and cheap, its production is safer and ecologically acceptable for the environment and human health, and it can provide an additional source of nitrogen for plants, thus meeting the needs of agricultural production for high and stable yields. In addition to its application to stimulate the growth and germination, recent pioneering research has demonstrated the positive potential of PAW to reduce pests in agricultural production. Many studies have demonstrated the ability of PAW in terms of strong antimicrobial activity, and as an economic and ecological agent it offers new opportunities in the food industry due to its nitrogen and oxygen components (reactive oxygen species).

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