Potatoes supplemented with phenolics from unused chokeberries by ultrasound-assisted osmotic treatment.

PANTELIDOU D., GEROGIANNIS K., GONAS C., GOULA A. M.

Department of Food Science and Technology, School of Agriculture, Forestry and Natural Environment, Aristotle University, 541 24 Thessaloniki, Greece

Phenolic compounds

- ✓ Secondary metabolites
- ✓ Provide health benefits and basic nutrition
- ✓ Antioxidant, antimutagenic, antifungal, and antimicrobial properties
- ✓ Obtained through modification of standard processes or addition of compounds with bioactive properties
- ✓ Attempts to enrich food products with phenolic compounds

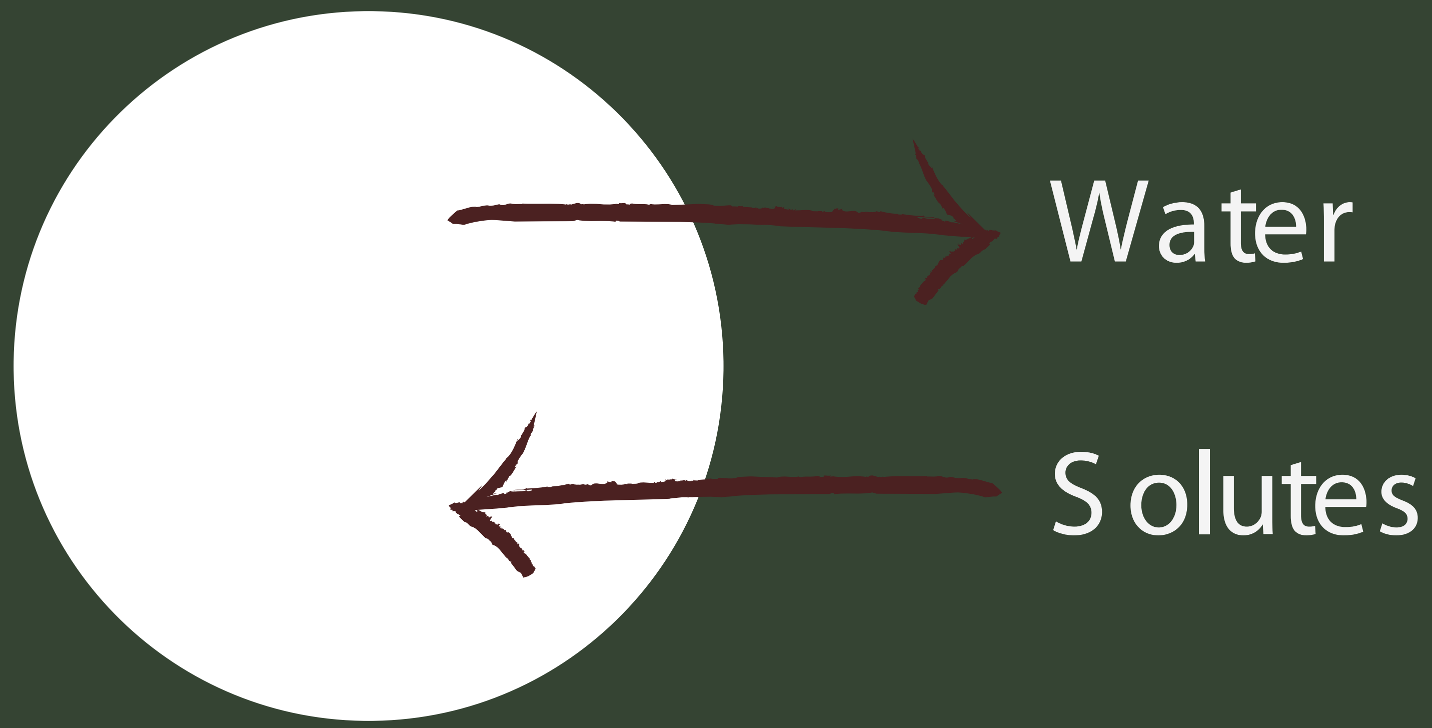
Osmotic treatment

Appropriate for formulating new products as it:

✓ Partially removes water

✓ Impregnates the product with solutes from the osmotic solution

It is, essentially, the placement of a raw material into a concentrated solution of soluble solids with higher osmotic pressure and lower water activity, that, due to osmosis, impels water to move through the selective permeable membrane, out of the product, and, at the same time, solutes move from the osmotic solution into the food material.



Low rate of mass transfer during osmotic dehydration

Several methods used to enhance the speed of the procedure:

- ✓ High pressure
- ✓ Partial vacuum
- ✓ Centrifugal force
- ✓ Pulsed electrical field
- ✓ Ultrasounds:

  A combination of ultrasounds and osmotic dehydration leads to the formation of microscopic channels in the intercellular tissue of the treated products due to the cavitation effect that takes place and it also generates agitation effects into the osmotic solution. Thus, it enhances mass transfer rate, without damaging the final product.

Chokeberry (Aronia melanocarpa)

One of the richest plant sources of phenolic compounds (1494-5292 mg/100g):

- ✓ Anthocyanins (141-2468 mg/100g) found in aronia are mainly derrivatives of of cyanidin of which the most abundant are cyanidin-3- galactoside (68.9%) and cyanidin-3-arabinoside (24.5%)
- ✓ Flavonols of which querqetin is the most abudant with 93.07% in total flavonol amount

Aronia's phenolic extracts are mainly used in the development of high nutritional value foods, such as:

- ✓ Supplementing confections
- ✓ Fruit fillings
- ✓ Sauces
- ✓ Beverages
- ✓ Pasta products

No reports of using them to infuse fresh solid foodstuff

Potatoes

- ✓ Fourth most important food crop in the world
- ✓ Osmotically dehydrated potato can be used as a quick-cooking product
- ✓ Food industry is looking for a way to make healthier snacks with functional and antioxidant prorerties

↓

Offers a chance for a functional snack that could increase the consumption of phenol rich product.

Objective

→ **To study**

The rate of phenolics infusion into potato cubes during osmotic dehydration

→ **To estimate**

The diffusion coefficients of water, solute, and phenolics during osmotic treatments

→ **To evaluate**

The possible enhancement of mass transfer due to ultrasounds application

Materials & methods

Raw materials

Potatoes:

- ✓ Washed and handpeeled
- ✓ Cut in 14mm side cubes

Maltodextrin:

- ✓ 12 Dextrose Equivalent

Sodium chloride

Aronia berries:

- ✓ Dried at 40 °C for 48h to a 9.5 ± 0.5 % moisture content
- ✓ Grounded (0.4 mm diameter particles) in a laboratory grinder

Phenolic extract

- ✓ Multiwave closed microwave system equipped with 6 sample vessels
- ✓ 50% aqueous ethanol solvent at a 24/1 mL/g ratio
- ✓ At microwave power of 400 W for 7 min.
- ✓ Extraction yield of 32.5 GAE/g of dry aronia

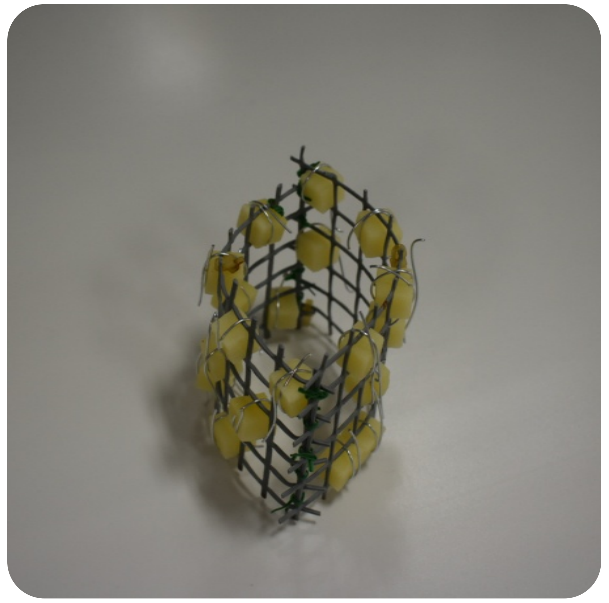
↓

- ✓ Evaporated under 150 mbar vacuum at 40 ^{o}C using a rotary evaporator

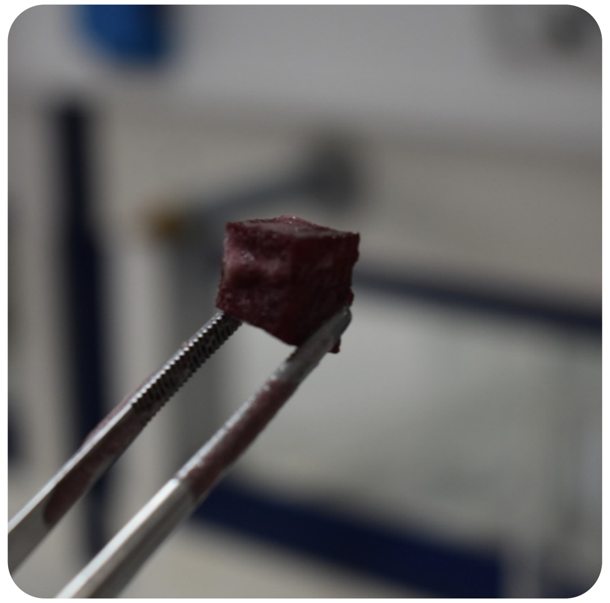
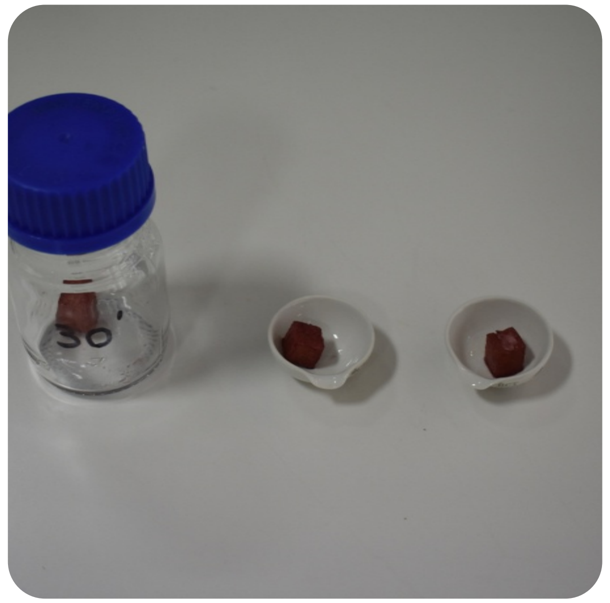
↓

Until 30% solid content.

Osmotic dehydration experiments



- ✓ T (20-45ºC)
- ✓ Ct (15-30%)
- ✓ CNaCl (0-12%)
- ✓ A (20-60%)
- ✓ Total of 31 experiments.

- ✓ Water Loss (WL)
- ✓ Solid Gain (SG)
- ✓ Phenolics Gain (PG)

Calculations

Mass and moisture and phenolic content data were used to calculate water loss (*WL*), solid gain (*SG*), and phenolics gain (*PG*) of the samples, according to the equations:

$$WL = \frac{w_i X_i - wX}{w_i}$$

$$SG = \frac{w_i S_i - wS}{w_i}$$

$$PG = \frac{w_i P_i - wP}{w_i}$$

Mathematical modeling

According to Fick's second law of diffusion:

$$MR = \frac{X - X_e}{X_i - X_e} = \frac{8^3}{\pi^6} \sum_{v=0}^{\infty} \frac{1}{(2v+1)^6} exp\left[-(2v+1)^2 \frac{3\pi^2 D_{Weff} t}{4L^2}\right]$$

$$SR = \frac{S - S_e}{S_i - S_e} = \frac{8^3}{\pi^6} \sum_{v=0}^{\infty} \frac{1}{(2v+1)^6} exp\left[-(2v+1)^2 \frac{3\pi^2 D_{Seff} t}{4L^2}\right]$$

$$PR = \frac{P - P_e}{P_i - P_e} = \frac{8^3}{\pi^6} \sum_{v=0}^{\infty} \frac{1}{(2v+1)^6} exp\left[-(2v+1)^2 \frac{3\pi^2 D_{Peff} t}{4L^2}\right]$$

To determine effective diffusivities:

$$\ln MR = \ln \frac{8^3}{\pi^6} - \frac{3\pi^2 D_{Weff}}{4L^2}$$

$$\ln SR = \ln \frac{8^3}{\pi^6} - \frac{3\pi^2 D_{Seff}}{4L^2}$$

$$\ln PR = \ln \frac{8^3}{\pi^6} - \frac{3\pi^2 D_{Peff}}{4L^2}$$

Microstructure analysis

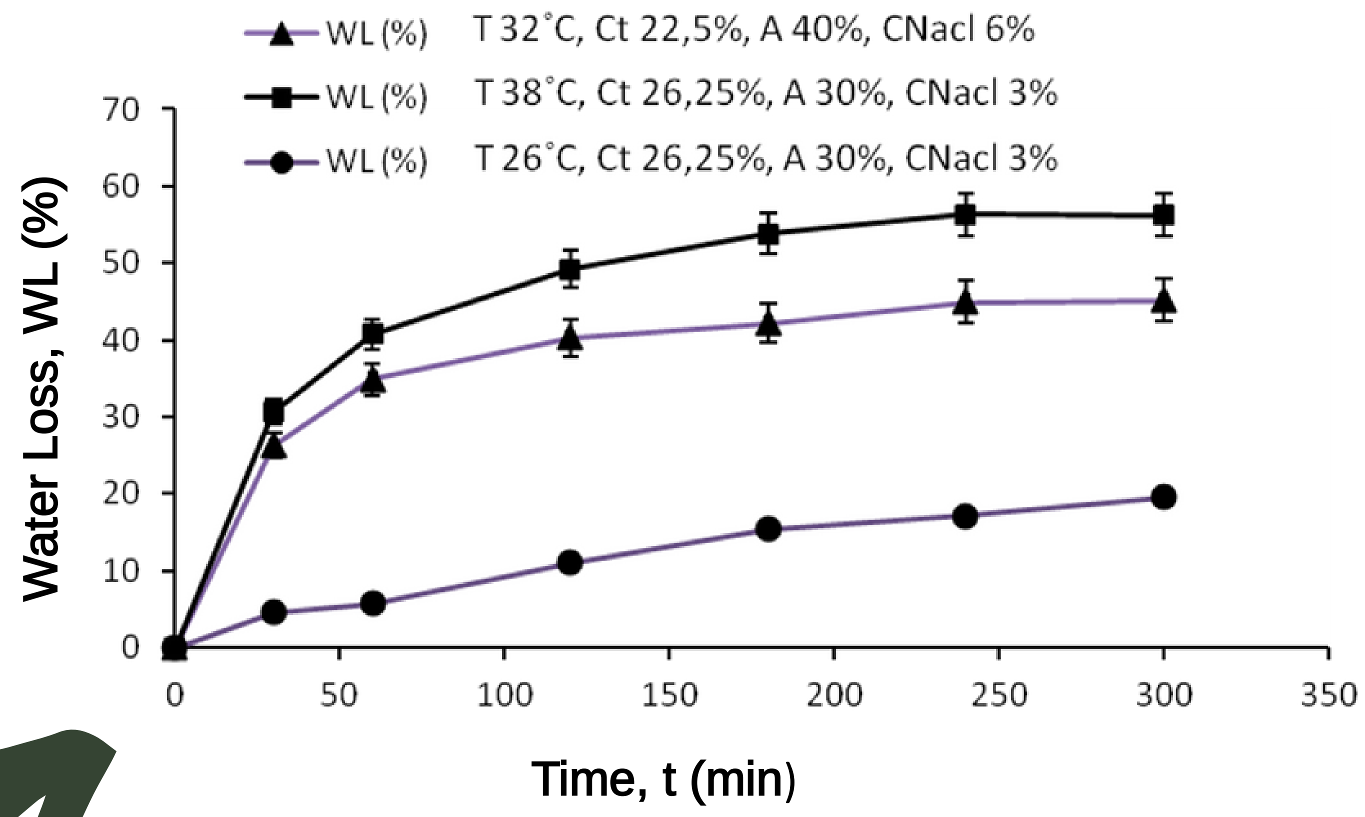
- ✓ SEM System (Quanta-200)
- ✓ Potatoes samples: dried, mounted on aluminium stubs with conductive adhesive and coated with gold
- ✓ x100 magnification

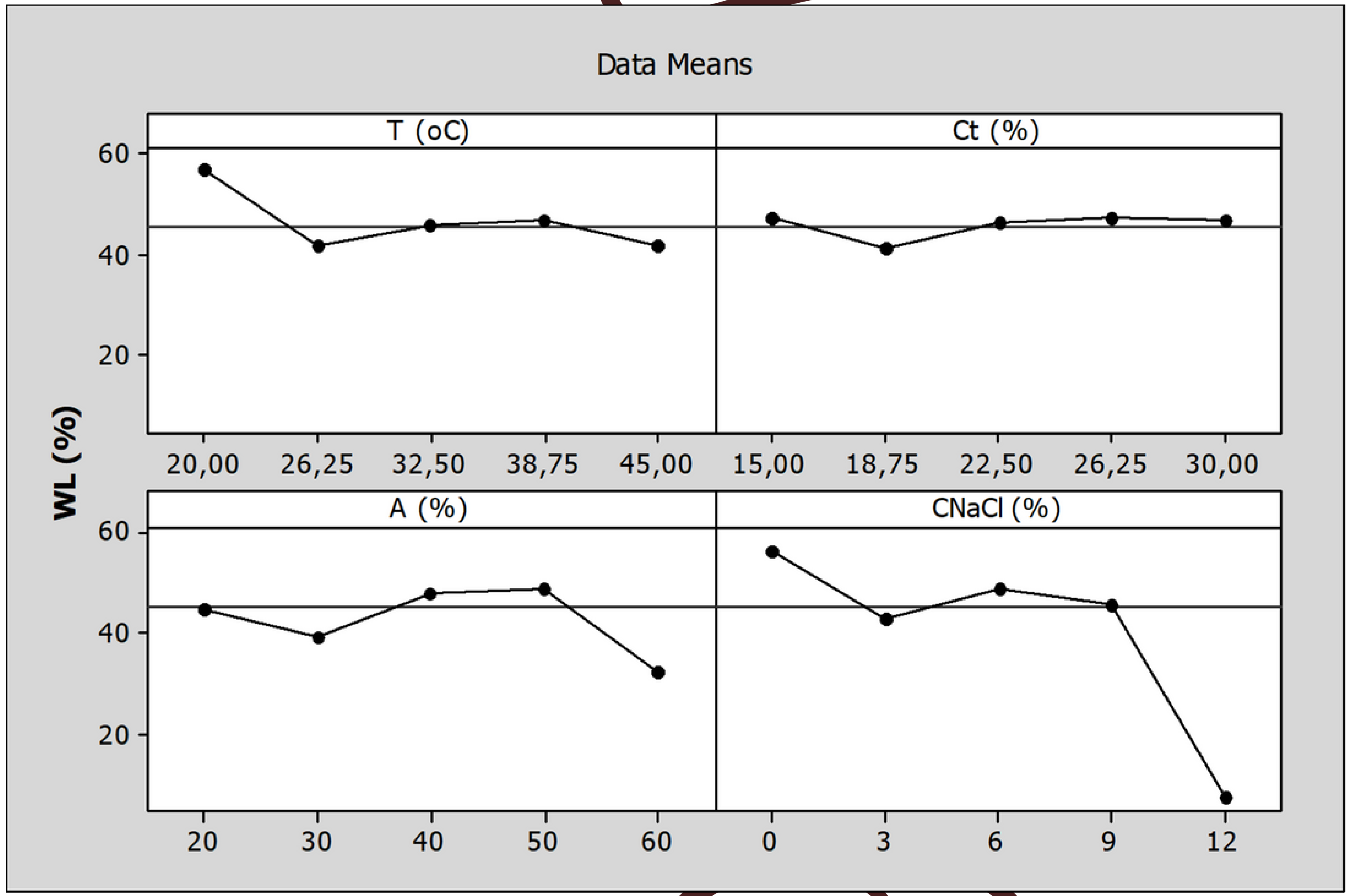
Statistical analysis

- ✓ Minitab™
- ✓ ANOVA
- ✓ p less than 0.05 was statistically significant

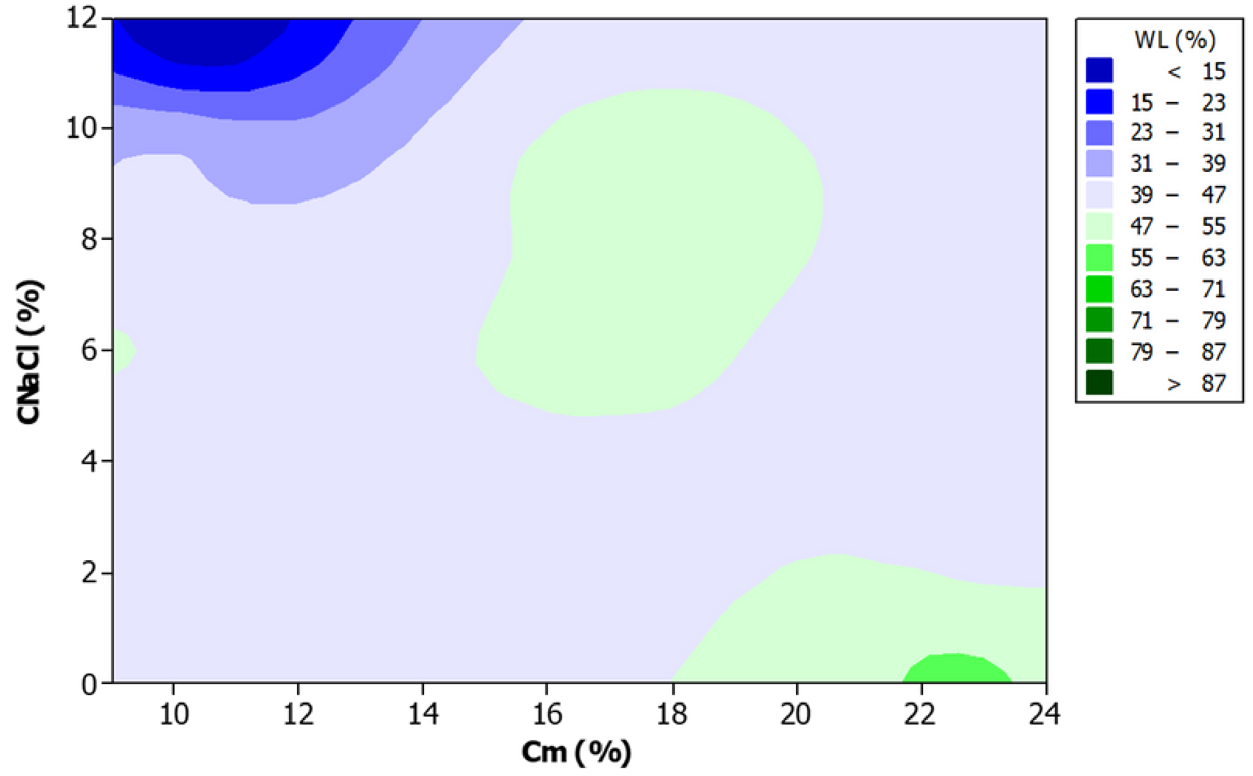
Results

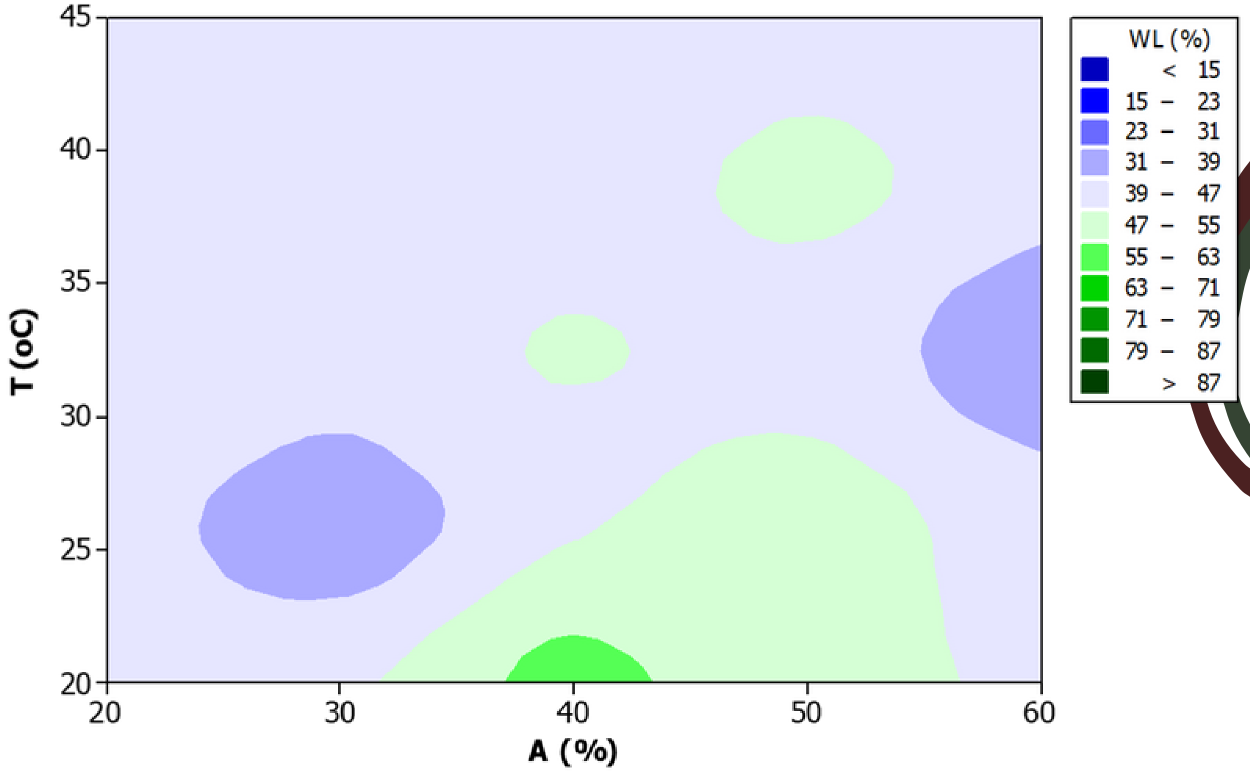
Water Loss

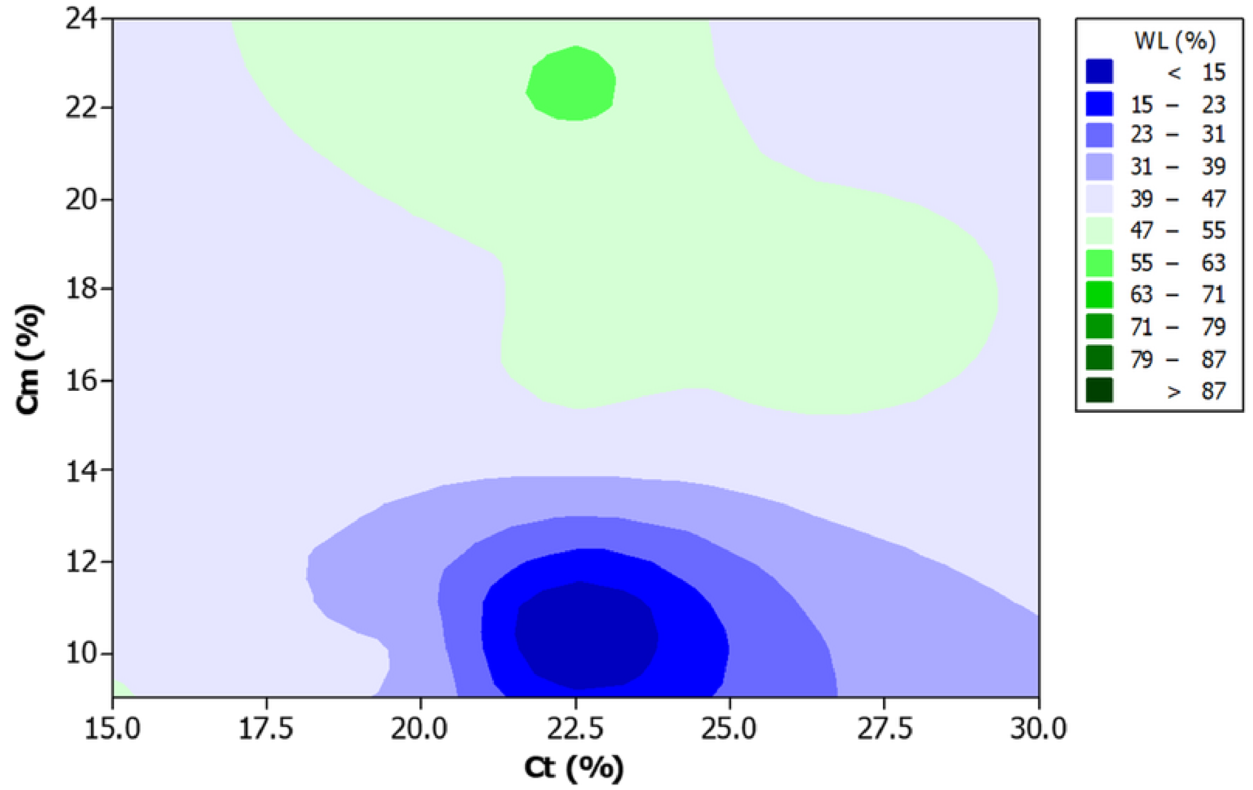




During the first hour of osmotic dehydration, the rate of increase in moisture loss is higher due to the difference in osmotic pressure between the sample and the surrounding hypertonic osmotic solution

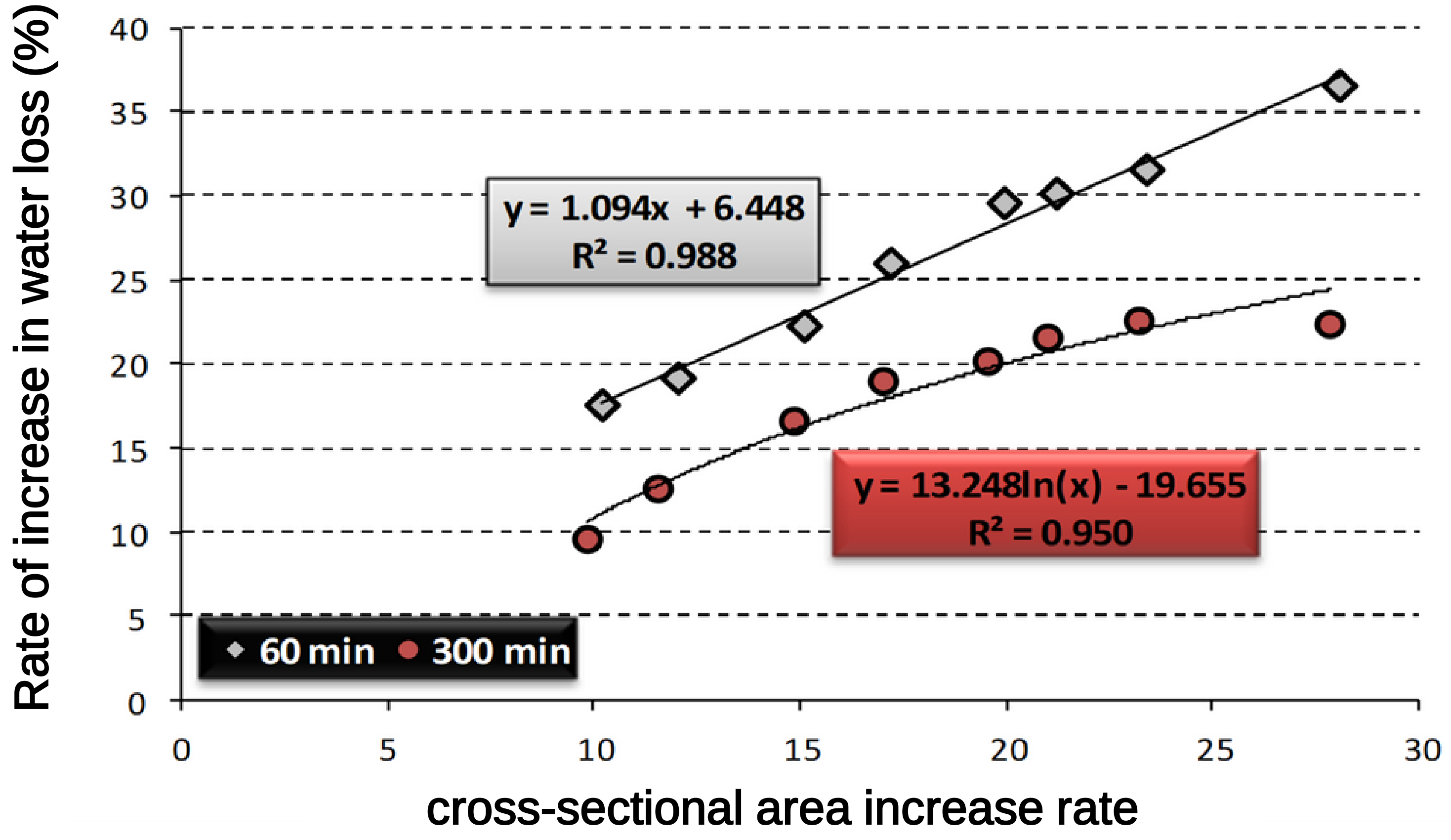






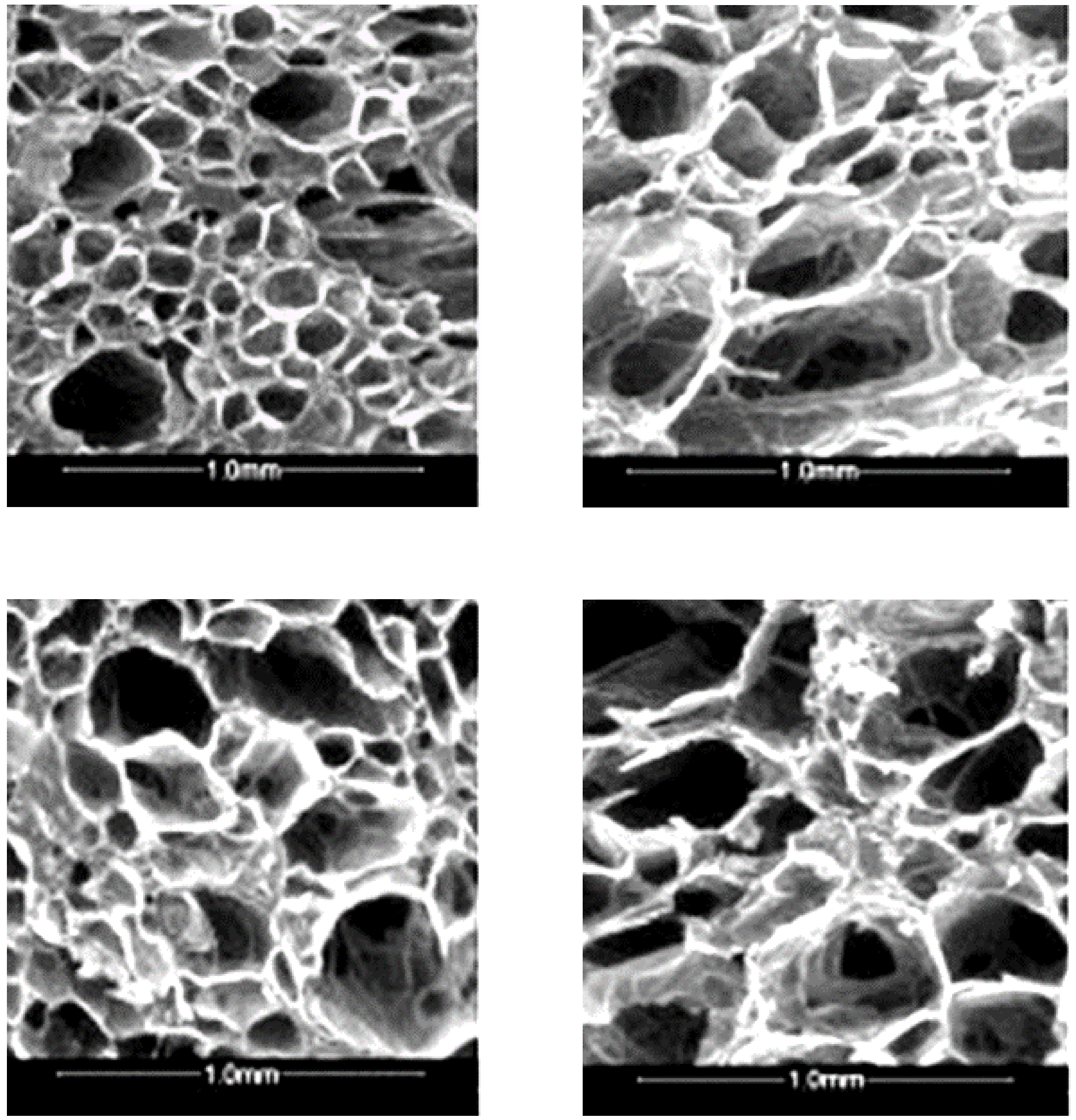
- ✓ Decrease in maltodextrin concentration causes a decrease in moisture loss.
- ✓ The observed decrease in water loss may be related to the decrease in maltodextrin concentration and not to the increase in NaCl concentration.

Effect of ultrasound on water loss



60 min.

300 min.



Using stirring

Using ultrasound power

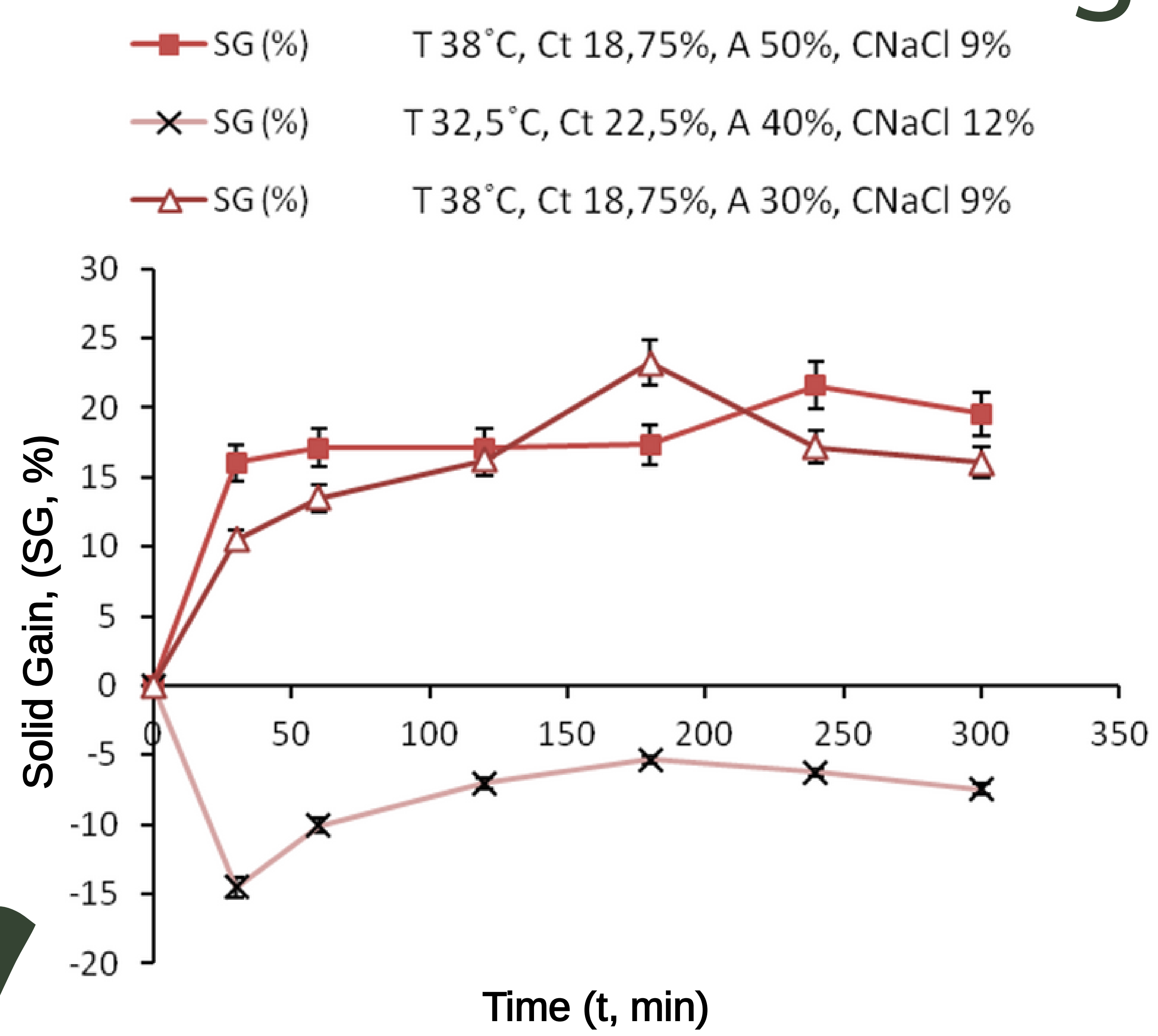
Regression Analysis for Water Loss

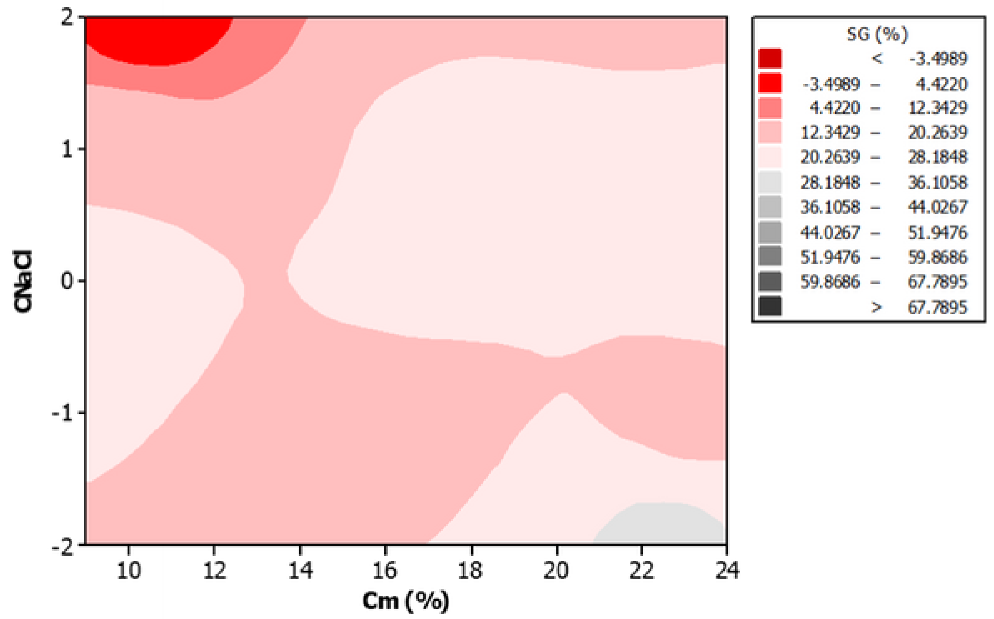
Term	Coef	SE Coef	t	p
Constant	52,005	6,047	8,600	0,000
T	0,522	3,266	0,160	0,875
C_{total}	1,855	3,266	0,568	0,578
A	2,216	3,266	0,678	0,507
C_{NaCl}	-3,174	3,266	-0,972	0,346
T*T	-0,204	2,992	-0,068	0,947
C_{total} * C_{total}	-0,834	2,992	-0,279	0,784
A*A	-2,969	2,992	-0,992	0,336
C_{NaCl}* C_{NaCl}	-4,624	2,992	-1,546	0,142
T* C_{total}	-1,482	4,000	-0,371	0,716
T*A	-3,209	4,000	-0,802	0,434
T* C_{NaCl}	-9,318	4,000	-2,330	0,033
C_{total} *A	-1,065	4,000	-0,266	0,793
C_{total} * C_{NaCl}	2,583	4,000	0,646	0,528
A* C_{NaCl}	-2,538	4,000	-0,635	0,535

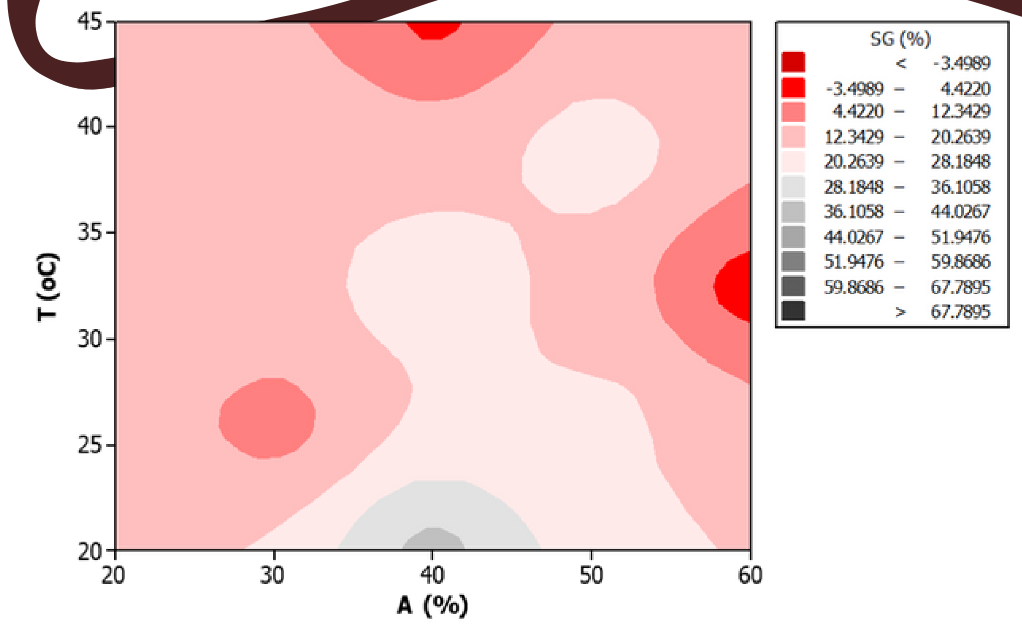
✓ Statistically significant parameters:

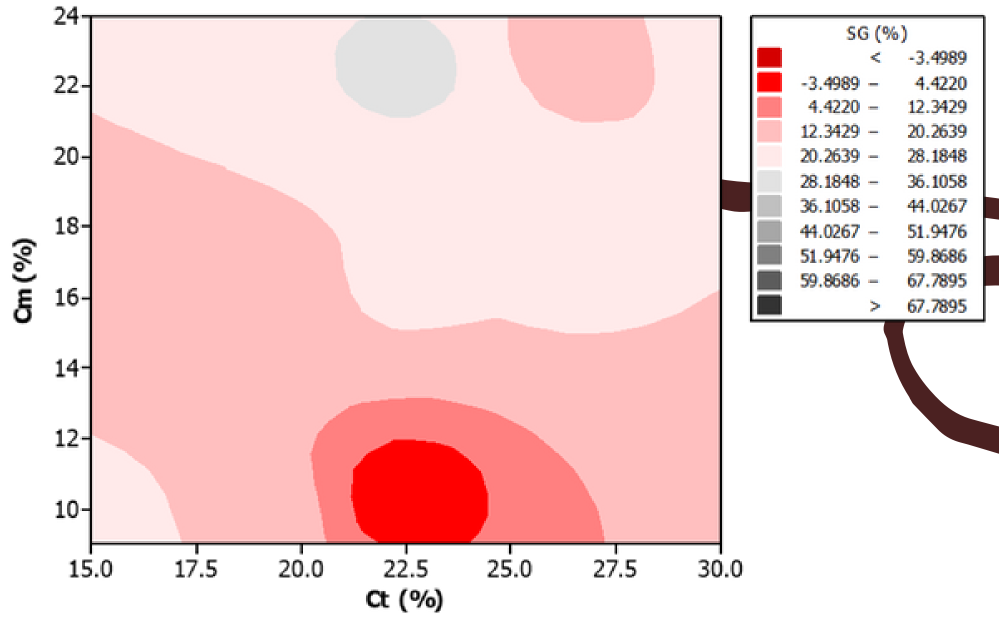
$p<0.05$

Solid Gain



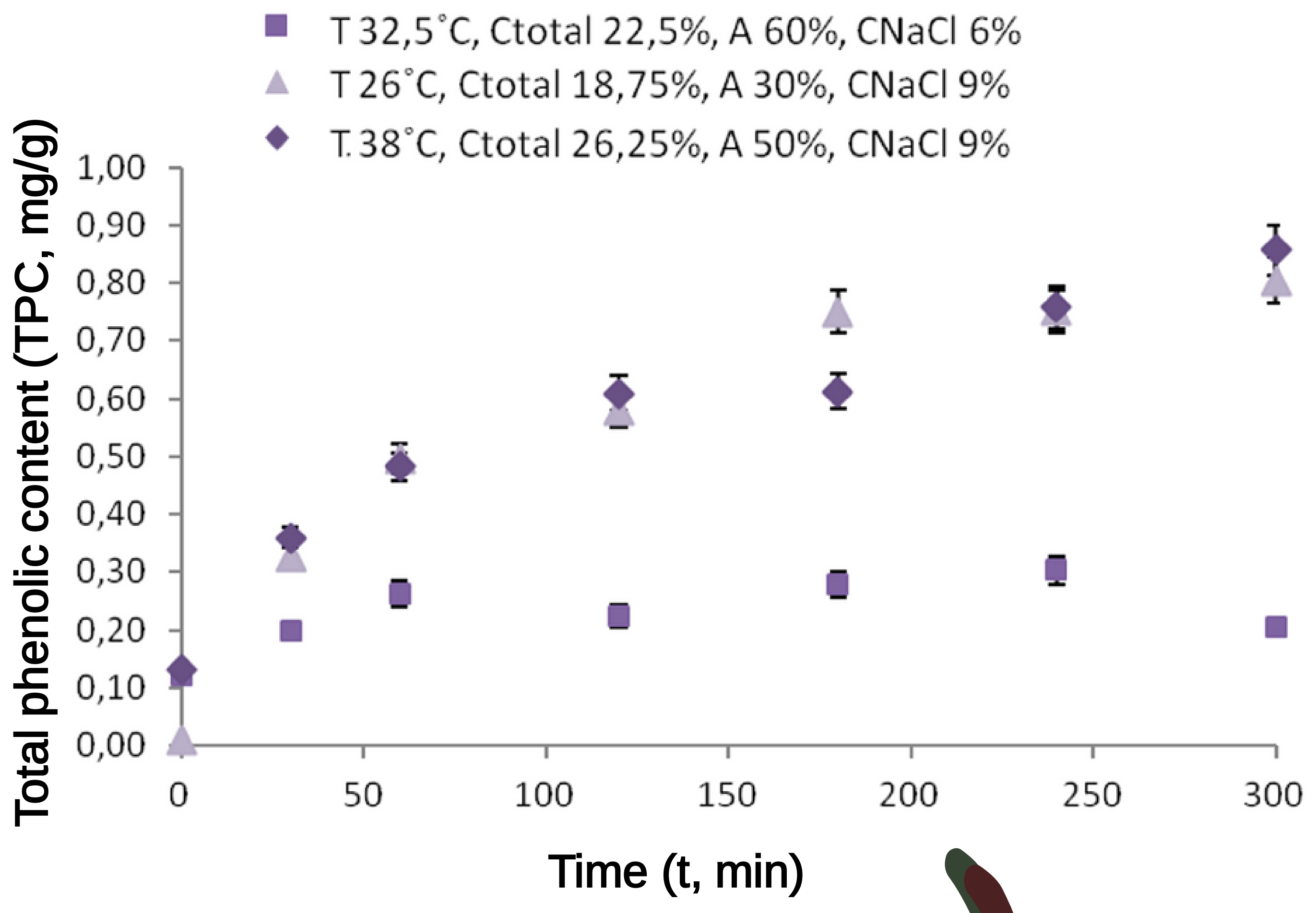




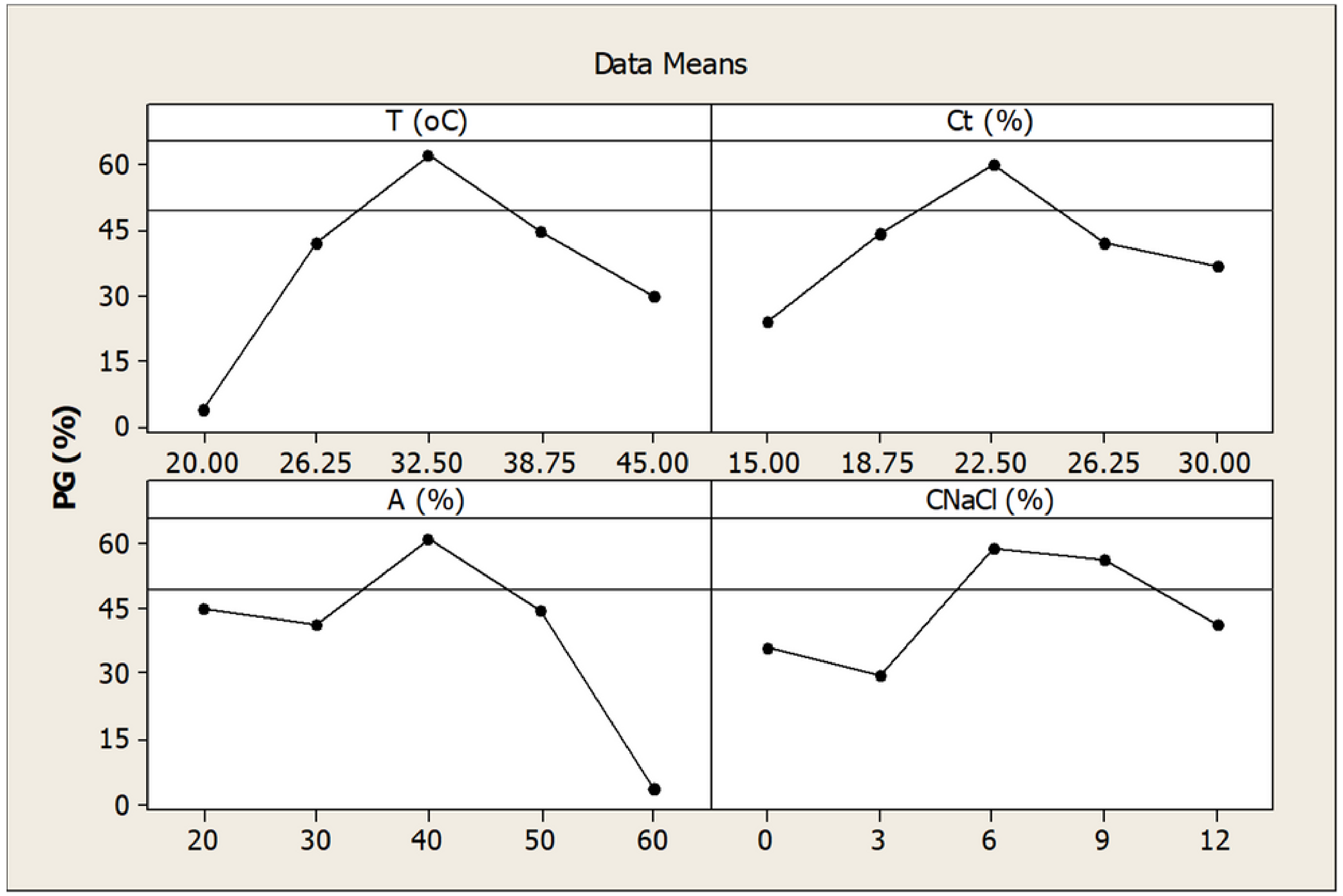


The rate of solids intake is lower than the rate of moisture loss
In some experiments, an initial loss of solids from the sample to the solution is observed, which over time is converted to solids uptake, but is at very low levels.

Phenolics Gain



- ✓ Maximum percentage of phenolic intake =103,1%
- ✓ Maximun concentration of phenolics =1,34 mg/g

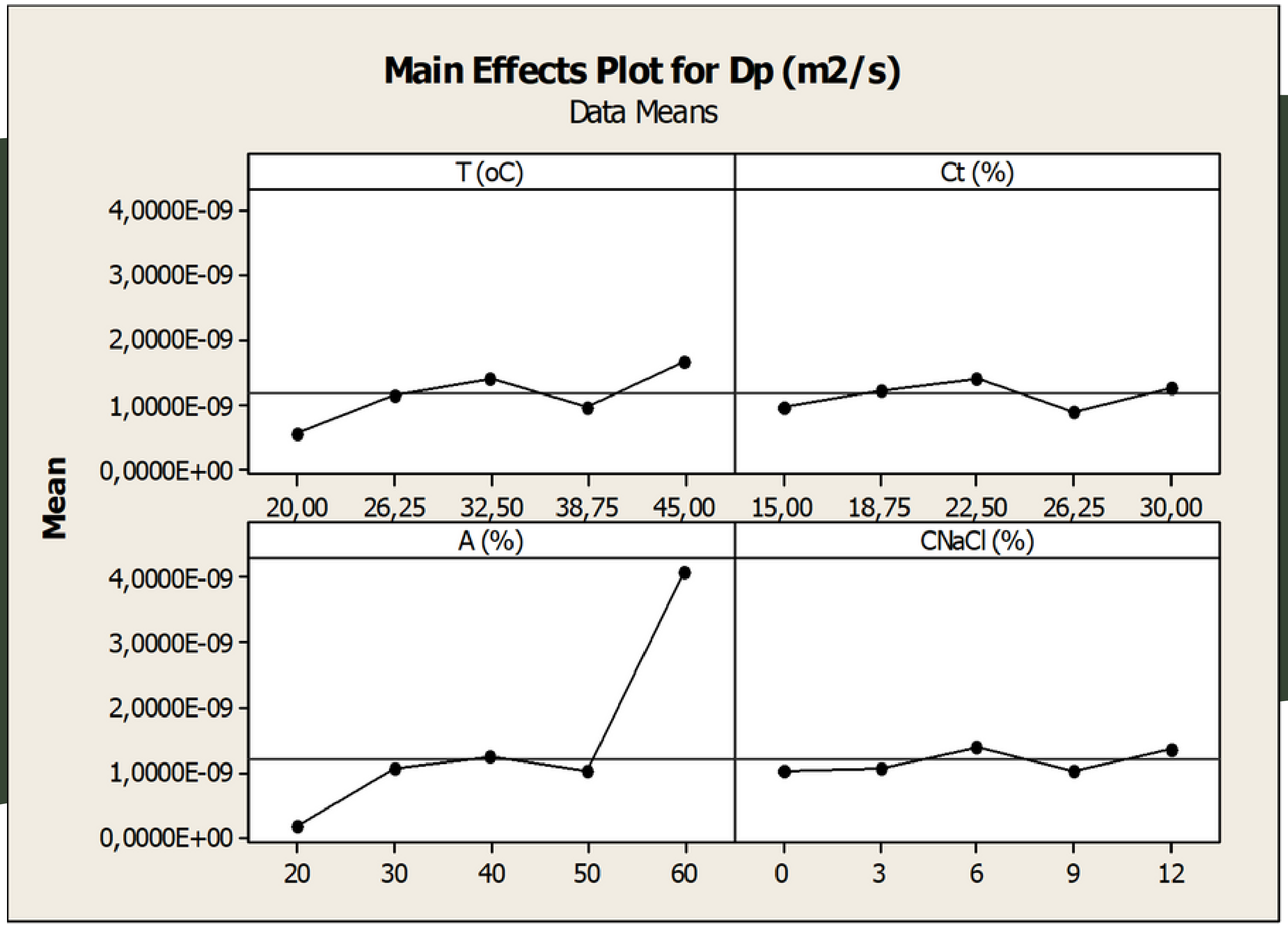


Mathematical modeling

	MOISTURE	SOLIDS	PHENOLICS
Simplified - Vconstant	$2{,}95 \cdot 10^{10} – 5{,}39 \cdot 10^{9}$	$5{,}26 \cdot 10^{10} – 6{,}91 \cdot 10^{9}$	$3{,}51 \cdot 10^{10} – 9{,}37 \cdot 10^{9}$
Simplified - Vvariable	$1{,}73 \cdot 10^{10} – 3{,}15 \cdot 10^{9}$	$2{,}47 \cdot 10^{10} – 3{,}26 \cdot 10^{9}$	$2{,}29 \cdot 10^{10} – 5{,}98 \cdot 10^{9}$
Analytical - Vconstant	$2 \cdot 10^{10} – 3{,}74 \cdot 10^{9}$	$3{,}54 \cdot 10^{10} – 4{,}71 \cdot 10^{9}$	$2{,}18 \cdot 10^{10} – 6{,}57 \cdot 10^{9}$
Analytical - Vvariable	$1{,}18 \cdot 10^{10} – 2{,}14 \cdot 10^{9}$	$1{,}67 \cdot 10^{10} – 2.37 \cdot 10^{9}$	$1{,}65 \cdot 10^{10} – 4{,}07 \cdot 10^{9}$

- ✓ The simplified method gives values that are significantly different and, in particular, higher than the analytical method.

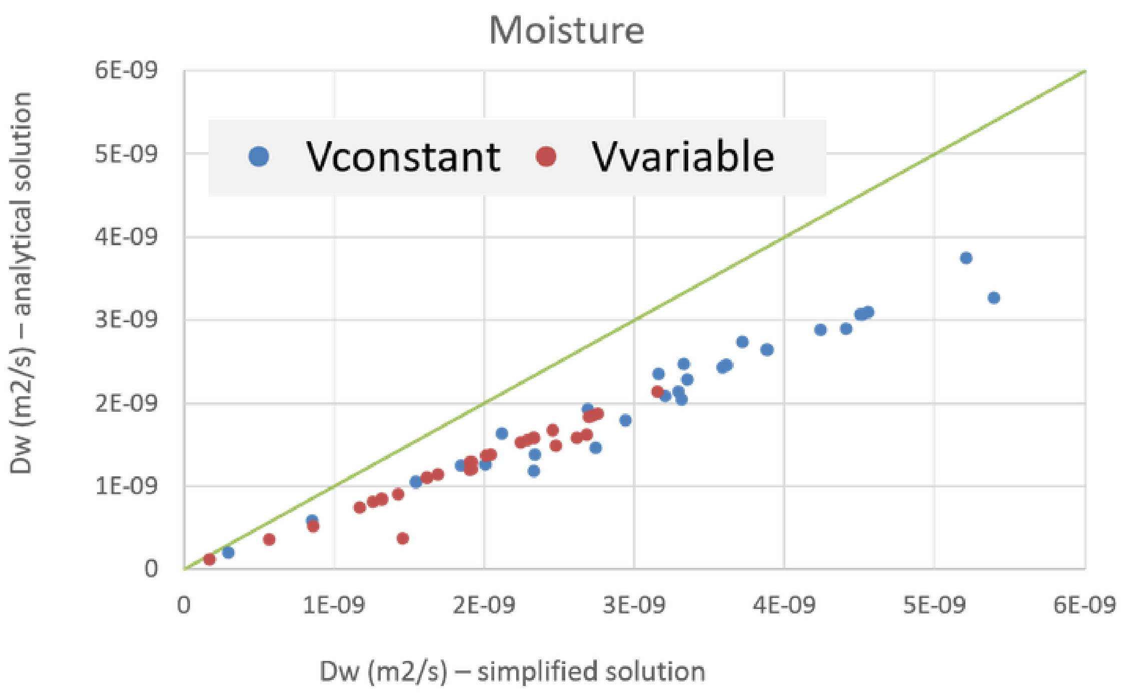
Diffusion Coefficient for Phenolic Gain

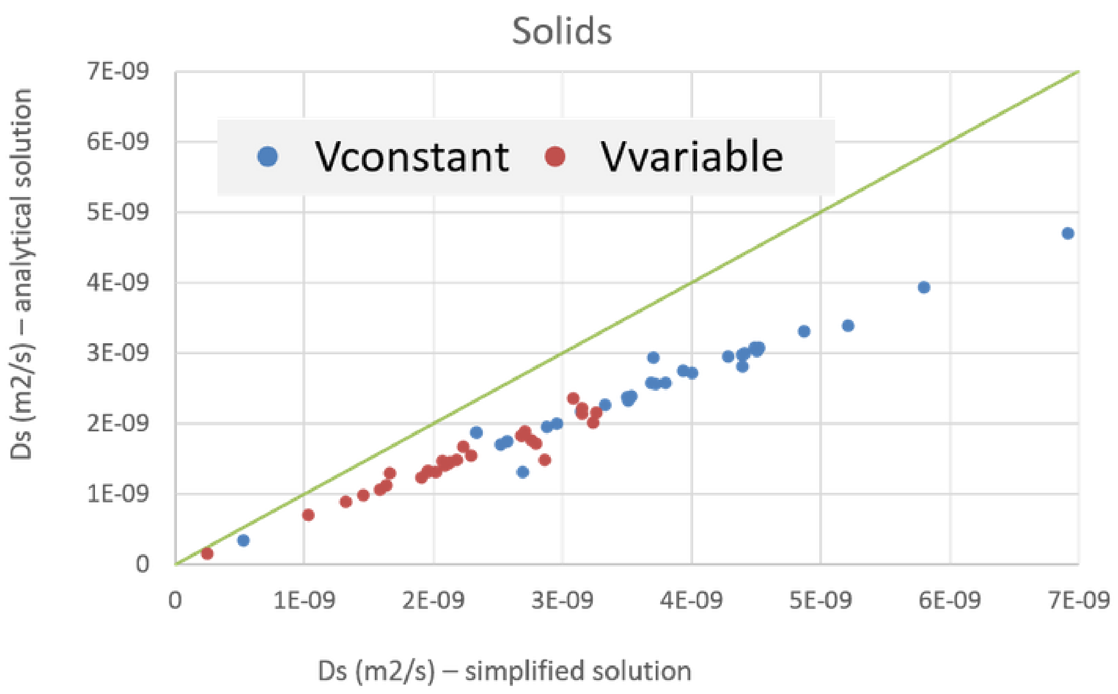


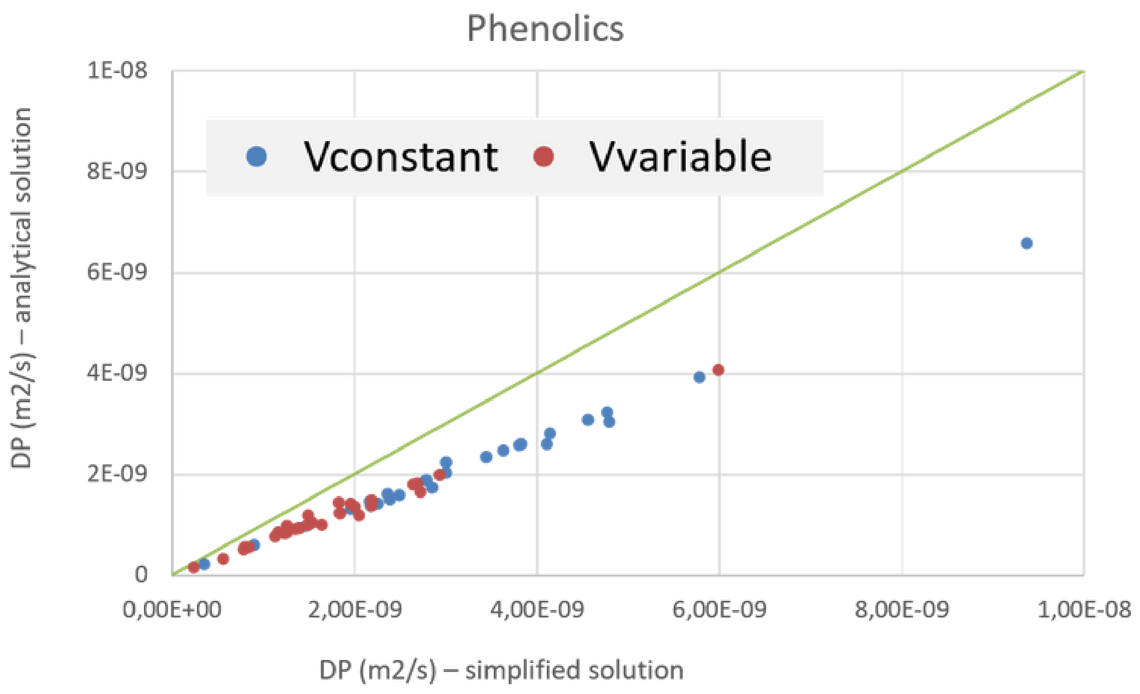
- ✓ Increase of the total solids concentration was shown to favor the uptake of phenolic substances in potato samples, with an optimal concentration of 22.50%
- ✓ An intensity of 40% significantly helped to enrich the potato cubes with phenolic components

- ✗ 20 ˚C & 45˚C had a negative impact on the uptake of phenolic compounds in the food matrix
- The sodium chloride concentration did not appear to affect to the same extent as the other factors the uptake of phenolic compounds into potato cubes

Comparison of simplified and analytical solution

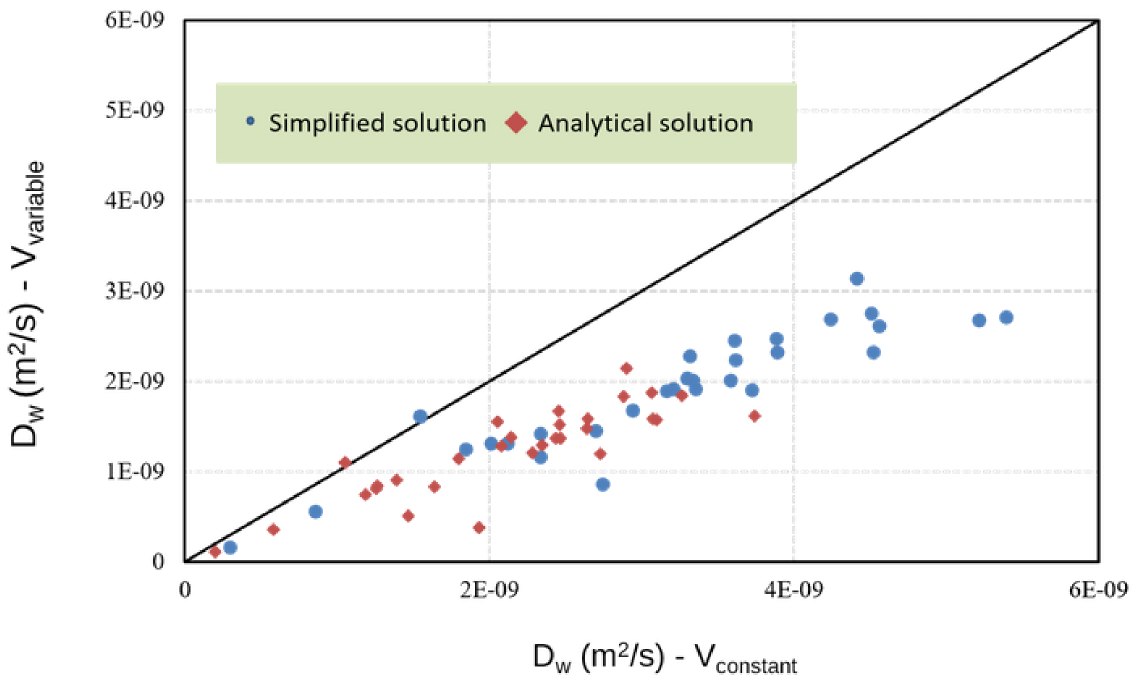




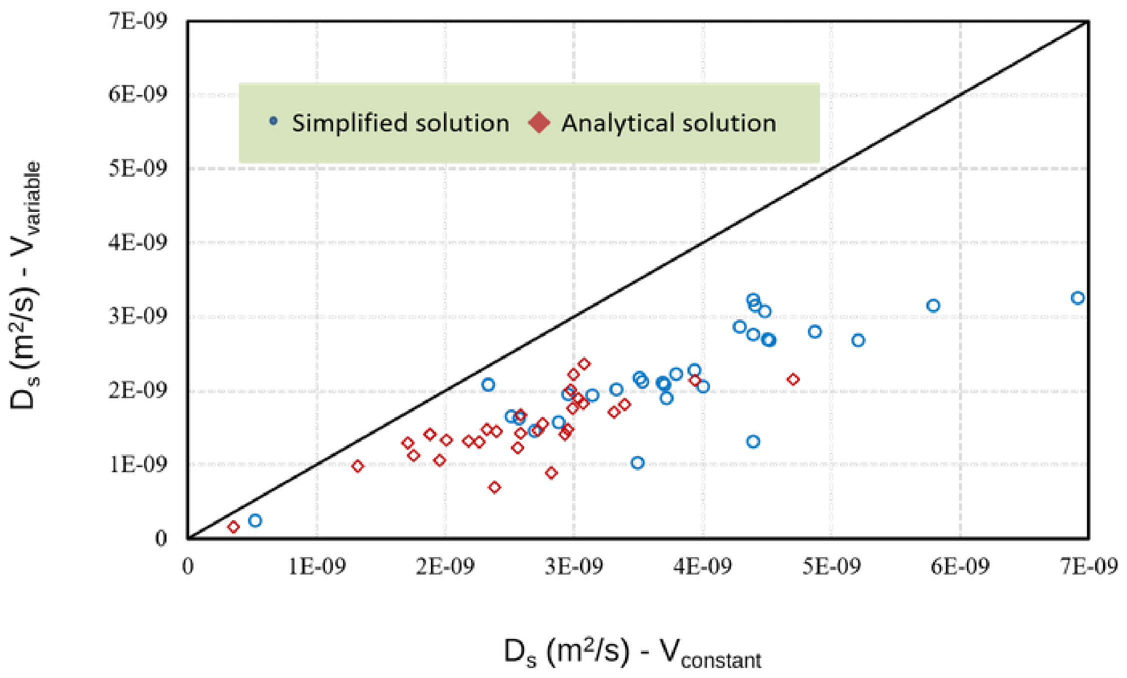


Comparison of V constant and V variable hypothesis

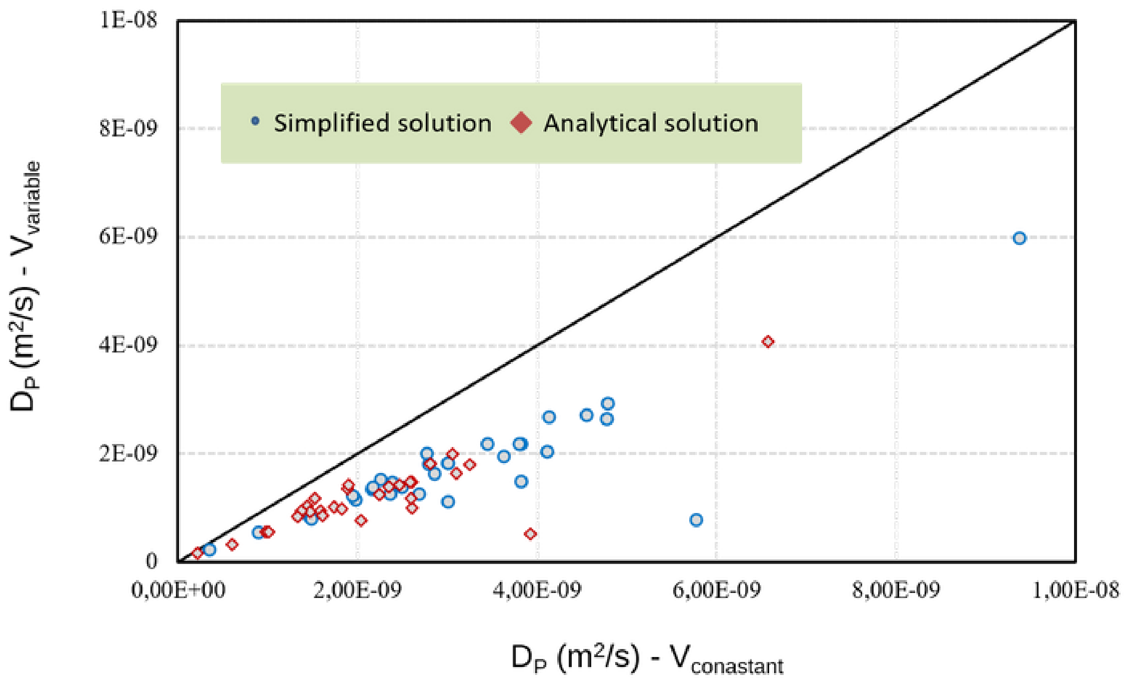
Moisture



Solids



Phenolics



Conclusions

Conclusions

- Osmotic treatment was proved to be a feasible method to incorporate phenolic compounds in potato cubes without altering their structure.

  Total phenolic content similar to that of the richest fruits, about 1.34 mg/g

- The mass transfer rate for solids gain is slower than that of water loss because of the resistant characteristic of cell wall and the higher molecular weight of solute.
- The factors of temperature, total solids concentration of the osmotic solution, and intensity of ultrasounds had a significant effect.

  Temperature = 32,5 °C
  Osmotic solution concentration = 22,5 % w/w
  C_{NaCl} = 6 % w/w

- The values of diffusion coefficients are lower when volume change is considered in their estimation.

Thank you for your attention

Literature

1. Antonio, G. C., Alves, D. G., Azoubel, P. M., Murr, F. E., & Park, K. J. (2008). Influence of osmotic dehydration and high temperature short time processes on dried sweet potato (Ipomoea batatas Lam.). *Journal of Food Engineering, 84*, pp. 375-382. doi:https://doi.org/10.1016/j.jfoodeng.2007.05.033
2. Azarpazhooh, E., Sharayei, P., & Ramaswamy, H. S. (2020). Optimization of ultrasound-assisted osmotic treatment of Aleo vera gel impregnated with grape pomace phenolic compounds using response surface methodology. *Agricultural Engineering International: CIGR Journal, 22*, pp. 202-212.
3. Azoubel, P. M., & Murr, F. E. (2004). Mass transfer kinetics of osmotic dehydration of cherry tomato. *Journal of Food Engineering, 61*, pp. 291-295. doi:https://doi.org/10.1016/S0260-8774(03)00132-8
4. Balaban, M. O. (1990). Effect of volume change in foods on the temperature and moisture content predictions of simultaneous heat and moisture transfer models. *Journal of Food Process Engineering, 12*, pp. 67-88. doi: https://doi.org/10.1111/j.1745-4530.1990.tb00041.x
5. Barat, J. M., Chiralt, A., & Fito, P. (1998). Equilibrium in cellular food osmotic solution systems as related to structure. *Journal of Food Science, 63*, pp. 836-840.
6. Bchir, B., Besbes, S., Attia, H., & Blecker, C. (2009). Osmotic dehydration of pomegranate seeds: mass transfer kinetics and differential scanning calorimetry characterization. *International journal of food science & technology, 44*, pp. 2208-2217. doi: https://doi.org/10.1111/j.1365-2621.2009.02061.x
7. Bellary, A. N., Sowbhagya, H. B., & Rastogi, N. K. (2011). Osmotic dehydration assisted impregnation of curcuminoids in coconut slices. *Journal of Food Engineering, 105*, pp. 453-459. doi:https://doi.org/10.1016/j.jfoodeng.2011.03.002
8. Bermúdez-Aguirre, D., Mobbs, T., & Barbosa-Cánovas, G. V. (2011). Ultrasound applications in food processing. In H. Feng, G. Barbosa-Canovas, & J. Weiss, *Ultrasound Technologies for Food and Bioprocessing. Food Engineering Series.* (pp. 65-105). New York: Springer. doi:https://doi.org/10.1007/978-1-4419-7472-3_3
9. Cárcel, J. A., Benedito, J., Rosselló, C., & Mulet, A. (2007). . Influence of ultrasound intensity on mass transfer in apple immersed in a sucrose solution. *Journal of food engineering, 78*, pp. 472-479. doi:https://doi.org/10.1016/j.jfoodeng.2005.10.018
10. Cheng, X. F., Zhang, M., Adhikari, B., & Islam, M. N. (2014). Effect of power ultrasound and pulsed vacuum treatments on the dehydration kinetics, distribution, and status of water in osmotically dehydrated strawberry: a combined NMR and DSC study. *Food and bioprocess technology, 7*, pp. 2782-2792. doi:https://doi.org/10.1007/s11947-014-1355-1
11. Corrêa, J. L., Justus, A., de Oliveira, L. F., & Alves, G. E. (2015). Osmotic dehydration of tomato assisted by ultrasound: evaluation of the liquid media on mass transfer and product quality. *International journal of food engineering, 11*, pp. 505-516.
12. Denev, P., Kratchanova, M., Petrova, I., Klisurova, D., Georgiev, Y., Ognyanov, M., & Yanakieva, I. (2018). Black chokeberry (Aronia melanocarpa (Michx.) Elliot) fruits and functional drinks differ significantly in their chemical composition and antioxidant activity. *Journal of Chemistry*, pp. 1-11. doi:https://doi.org/10.1155/2018/9574587
13. Deng, Y., & Zhao, Y. (2008). Effects of pulsed-vacuum and ultrasound on the osmodehydration kinetics and microstructure of apples (Fuji). *Journal of Food Engineering, 85*, pp. 84-93. doi:https://doi.org/10.1016/j.jfoodeng.2007.07.016
14. Eren, İ., & Kaymak-Ertekin, F. (2007). Optimization of osmotic dehydration of potato using response surface methodology. *Journal of food engineering*, pp. 344-352. doi:https://doi.org/10.1016/j.jfoodeng.2006.01.069
15. Falade, K. O., Igbeka, J. C., & Ayanwuyi, F. A. (2007). Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon. *Journal of Food Engineering, 80*, pp. 979-985. doi:https://doi.org/10.1016/j.jfoodeng.2006.06.033
16. Farhaninejad, Z., Fathi, M., Shahedi, M., & Sadeghi, M. (2015). Osmotic dehydration of banana slices using direct and indirect sonication: optimization and microstructure analysis. *Journal of Food Process Engineering, 40*, pp. 1-10. doi: https://doi.org/10.1111/jfpe.12336
17. Fernandes, F. A., Gallão, M. I., & Rodrigues, S. (2009). Effect of osmosis and ultrasound on pineapple cell tissue structure during dehydration. *Journal of Food Engineering, 90*, pp. 186-190. doi:https://doi.org/10.1016/j.jfoodeng.2008.06.021
18. Fernandes, F. A., Linhares Jr, F. E., & Rodrigues, S. (2008). Ultrasound as pre-treatment for drying of pineapple. *Ultrasonics Sonochemistry, 15*, pp. 1049-1054. doi:https://doi.org/10.1016/j.ultsonch.2008.03.009
19. Ganjloo, A., Rahman, R. A., Bakar, J., Osman, A., & Bimakr, M. (2011). Mathematical modelling of mass transfer during osmotic dehydration of seedless guava (Pisidium guajava L.) cubes. *International Food Research Journal, 18*, pp. 1105-1110.
20. Garcia-Noguera, J., Weller, C. L., Oliveira, F. I., Rodrigues, S., & Fernandes, F. A. (2010). Dual-stage sugar substitution in strawberries with a Stevia-based sweetener. *Innovative Food Science & Emerging Technologies, 11*, pp. 225-230. doi:https://doi.org/10.1016/j.ifset.2009.07.001
21. Genina-Soto, P., Barrera-Cortes, J., Gutierrez-Lopez, G., & Nieto, E. A. (2001). Temperature and concentration effects of osmotic media on OD profiles of sweet potato cubes. *Drying Technology, 19*, pp. 547-558. doi:https://doi.org/10.1081/DRT-100103933
22. Goula, A. M., Chasekioglou, A. N., & Lazarides, H. N. (2015). Drying and shrinkage kinetics of solid waste of olive oil processing. *Drying Technology, 33*, pp. 1728-1738. doi:https://doi.org/10.1080/07373937.2015.1026983
23. Goula, A. M., Kokolaki, M., & Daftsiou, E. (2017). Use of ultrasound for osmotic dehydration. The case of potatoes. *Food and bioproducts processing, 105*, pp. 157-170. doi:https://doi.org/10.1016/j.fbp.2017.07.008
24. Goula, A. M., Ververi, M., Adamopoulou, A., & Kaderides, K. (2017). Green ultrasound-assisted extraction of carotenoids from pomegranate wastes using vegetable oils. *Ultrasonics sonochemistry, 34*, pp. 821-830. doi:https://doi.org/10.1016/j.ultsonch.2016.07.022
25. Guerra-Valle, M. E., Moreno, J., Lillo-Pérez, S., Petzold, G., Simpson, R., & Nuñez, H. (2018). Enrichment of apple slices with bioactive compounds from pomegranate cryoconcentrated juice as an osmodehydration agent. *Journal of Food Quality*, pp. 1-9. doi:https://doi.org/10.1155/2018/7241981
26. Hatamipour, M. S., & Mowla, D. (2003). Experimental and theoretical investigation of drying of carrots in a fluidized bed with energy carrier. *Drying Technology, 21*, pp. 83-101. doi:https://doi.org/10.1081/DRT-120017285
27. Iqbal, S., Haleem, S., Akhtar, M., Zia-ul-Haq, M., & Akbar, J. (2008). Efficiency of pomegranate peel extracts in stabilization of sunflower oil under accelerated conditions. *Food Research International, 41*, pp. 194-200. doi:https://doi.org/10.1016/j.foodres.2007.11.005
28. Islam, M. N., & Flink, J. N. (1982). Dehydration of potato: II. Osmotic concentration and its effect on air drying behaviour. *International Journal of Food Science & Technology, 17*, pp. 387-403. doi: https://doi.org/10.1111/j.1365-2621.1982.tb00194.x
29. Jakobek, L., Šeruga, M., Medvidović-Kosanović, M., & Novak, I. (2007). Antioxidant activity and polyphenols of Aronia in comparison to other berry species. *Agriculturae Conspectus Scientificus, 72*, pp. 301-306.
30. Kaderides, K., Mourtzinos, I., & Goula, A. M. (2020). Stability of pomegranate peel polyphenols encapsulated in orange juice industry by-product and their incorporation in cookies. *Food chemistry, 310*, pp. 1-8. doi:https://doi.org/10.1016/j.foodchem.2019.125849
31. Karami, Z., Yousefi, G. H., & Emam-Djomeh, Z. (2013). Modeling and optimization of ultrasound-assisted osmotic dehydration with finished freeze drying on black cherries—the effect on antioxidant activities. *Journal of Food Biosciences and Technology, 3*, pp. 11-22.