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Energy and exergy analyses in microwave drying of orange slices

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Abstract

The orange samples were cut into slices with a thickness of 4 mm and treated with ohmic method for 3, 5, and 7 min as ohmic pre-treatment in three voltages 30, 50 and 70 V. Then, they were dried in three replicates using a microwave dryer and at three powers of 90, 360, and 900 W. The statistical analysis results showed that the ohmic time, ohmic voltage and microwave power are significant for the energy and exergy efficiency and specific energy and exergy loss at 1% level. The highest energy and exergy efficiency was observed at 900 W and in the ohmic time of 7 min. The highest energy and exergy efficiency was observed at 59.041% and 47.76%, respectively. The maximum energy loss was seen at 90 W and ohmic time of 3 min. The microwave power, ohmic time and ohmic voltage were statistically significant for all the parameters (energy and exergy) such that with increasing them, the energy and exergy efficiency increased, while the specific exergy and energy loss decreased.

Keywords: Microwave, Orange, Ohmic pre-treatment, Energy and Exergy.

Introduction

Preservation of food through drying is one of the oldest and the most widespread method that can be used to enhance the strength of the food. Food drying is removing the moisture so that the product can be stored for a long time and be protected against deterioration (Min *et al.* 2005). Drying reduces the amount of enzymatic activity and reduces the rate of the chemical reaction. It also increases the shelf life of food, reducing the weight and volume of food in packaging and transportation equipment, and can be controlled and stored in stores using drying.(Azadbakht *et al.* 2018). In fact, drying is a process that requires high energy consumption due to the high latent heat of water evaporation, and in the food industry, this process uses up for 10% of total energy consumption. Therefore, the energy consumed in drying crops is of great importance for industrial use (Azadbakht *et al.* 2017). Microwave drying is one of the important drying methods. Because of the better focus of energy on the product, the removal of moisture is faster and, compared to other methods, it requires only 20 to 35% space compared to other drying methods (Sharma and Prasad 2006; Wray and Ramaswamy 2015). Also, the thermodynamic analysis and especially exergy analysis in thermodynamic analysis have an essential role in the design and evaluation of thermal systems. Exergy thermodynamic analysis describes the maximum useful work produced by equilibrium heat and analyzed for exergy analysis, several points need to be evaluated, which can be useful in the design of dryers. (Dincer 2000; Dincer 2002). Drying fruits and vegetables is one of the most energy-consuming processes and therefore the drying speed should be increased to reduce the drying rate and energy consumption. Crop skin is one of the most important factors in reducing the rate of moisture removal in crops. It acts as a major resistance to moisture transfer from the interior to the surface. Crop pre-treatment is an important step in the drying process for crops that have been reported to be able to accelerate drying speed by removing wax and forming

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small cracks on the surface of the material to facilitate moisture. (Deshmukh *et al.* 2013).

Ohmic treatment is one of the electron heating methods based on the passage of electrical current through a food product having electrical resistance. The electrical energy is converted to heat while the amount of heat generated through the food product is directly related to the voltage gradient and the electrical conductivity. Ohmic heating as an alternate processing method has shown the potential to yield foods with higher quality compared to conventional heating. This difference is mainly due to its ability to heat materials rapidly and uniformly leading to less aggressive thermal treatment (Nouroallahi Soghani *et al.* 2018).

The use of pretreatment in the drying of products was also reported in the following studies: Darvishi et al. (2014) analyzed the energy and exergy of white mulberries in the process of drying with microwave dryer and reported that the specific energy loss increases with increasing microwave power.

Additionally, energy efficiency was reduced by decreasing the moisture content and microwave power. The best energy and exergy for white mulberry was observed at 100 W microwave power (Hosain Darvishi *et al*, 2014). Salengke et al. (2005) performed an experiment on the effect of ohmic pre-treatment on the drying rate of grapes and adsorption isotherm of raisins, which results from this study reveals that the drying rate of the grapes was significantly increased by the ohmic pre-treatment, especially at low electrical frequencies. The effect of the ohmic pre-treatment on the equilibrium moisture content of the raisins produced was evident at 0.75 or higher water activities but there was no or limited effect at low to moderate water activities (Salengke and Sastry 2005).

Nouroallahi Soghani et al. (2018) Performed an experiment on Ohmic blanching of white mushroom and its pre-treatment during microwave drying Which showed the results of this experiment blanched sample at low voltage and heating duration consumed the minimum total energy during the drying process. According to the drying is one of the important methods of the food industry and is a high energy consumption process, the purpose of this paper was to investigate the effect of ohmic pre-treatment on the energy and exergy value of the microwave dryer. In this investigation, the effect of ohmic voltage and ohmic time on energy and exergy rates were investigated.

Materials and methods

Sample preparation

Freshly harvested oranges (Tamson variety) were purchased from a local store in Gorgan city in Iran and were kept at 10℃ in the laboratory. At the beginning of each experiment, the oranges were washed and the slices were cut in a circular in a thickness of 4 mm and they were weighted. Then, samples were pretreated by ohmic method for 3, 5 and 7 min with 30, 50 and 70 voltage for 30, 60, and 90 min. The drying process was employed in a microwave dryer with 1.2, 4.8, and 12 W/g specific power density in the BioSystem Mechanics Department of Gorgan University of Agricultural Sciences and Natural Resources (Fig. 1). In figure 2, slice changes of samples before and after drying are shown.

Experimental method

Slices were pretreated and placed in containers and dried at three powers of 90, 360, and 900 W. The weight of oranges was measured using a 0.01 mg precision scale. The weight of each sample was measured and recorded at a time interval of 1 min to reach constant moisture. For each treatment, the experiments were repeated in triplicate. Environmental conditions for testing were conducted at a temperature of 20℃ and relative humidity of 71%. First, the oranges were equal to the slices of the same size, then the sample was placed inside the oven and the weight of the sample was measured according to the standards. Then, using Eq. 1, the moisture content was calculated (Yogendrasasidhar and Pydi Setty 2018).

$$MC = \frac{W - W\mathrm{e}}{W} \tag{1}$$

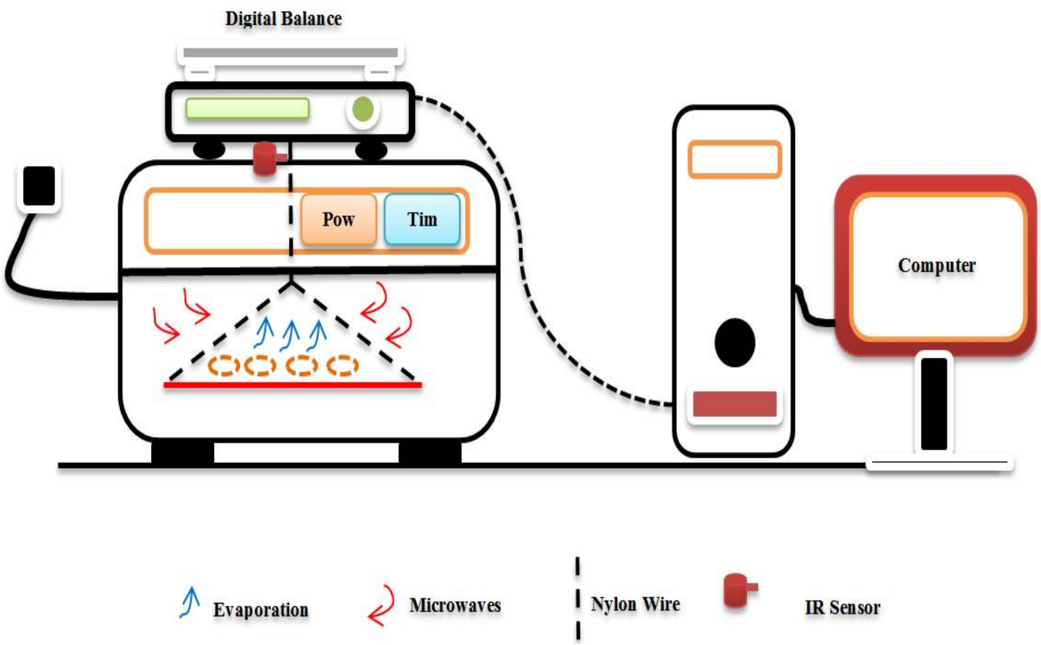

Fig. 1. Diagram of microwave drying system (Azadbakht et al, 2018)

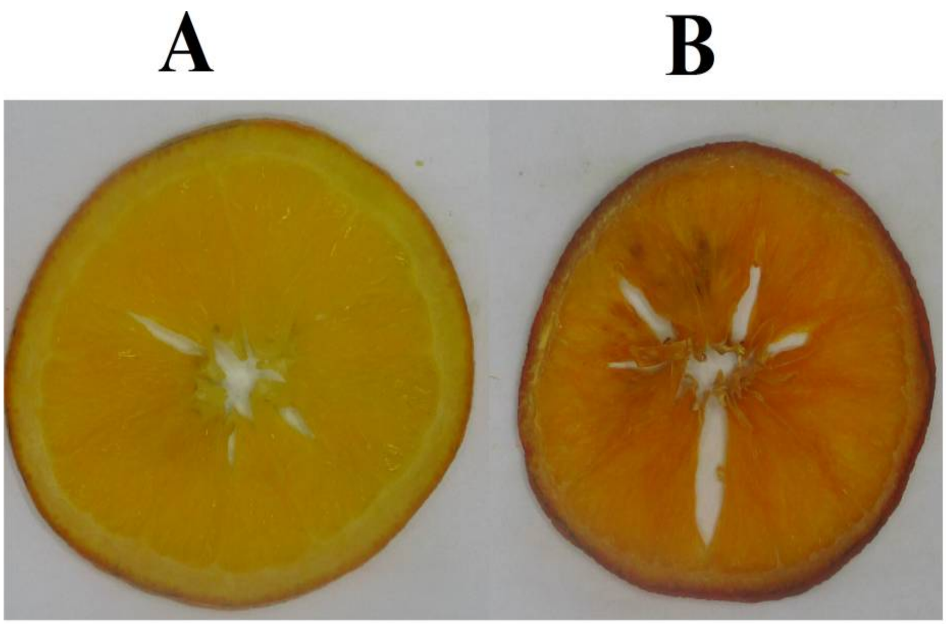

Fig. 2. Orange slice A: Before and B: After drying

Energy analysis

Energy used in the drying and heating process is important for production processes in both industrial and household sectors. However, the price of this energy is extremely expensive; therefore, there is a strong incentive to invent processes that will use energy efficiently. Currently, widely used drying and heating processes are complicated and inefficient and are generally damaging to the environment. Thus, it is required to have a simplified lower-cost approach replicable in a wide range of situations (Jindarat *et al.* 2011).

The mass and energy survival in the microwave dryers' chamber is shown in Fig. 3. The general relation of mass moisture survival is calculated using Eq. (2) (Darvishi *et al.* 2016).

$$\sum m_{in} = \sum m_{out} \quad (2)$$

According to Eq. 3, the initial mass of the sample is equal to the amount of water vapor removed and the rate of dried sample mass.

$$m_o = m_{ew} + m_p \quad (3)$$

The mass of evaporated water is obtained using Eq. 4 (Darvishi *et al.* 2014).

$$m_{wt} = m_d(M_0 - M_t) \quad (4)$$

The protected energy of the sensible heat, latent heat, and the thermal source of the microwave were calculated using Eq. 5 and the input energy of the dryer was calculated using Eq. 6 (Jindarat *et al.* 2011). In Eq. 5, the energy loss is $P_{ref} + P_{tra}$. Eq. 6 shows the input energy of the microwave. This formula is composed of three parts, including absorbed energy, reflected energy, and passed energy. In Eq. 6, $\left((mC_pT)_{dp} - (mC_pT)_{wp}\right) + \lambda_K m_{w)}$ equals to the absorbed energy of the product.

$$P_{in} = P_{abs} + P_{ref} + P_{tra} \quad (5)$$

$$P_{in} \times t = \left((mC_pT)_{dp} - (mC_pT)_{wp}\right) + \lambda_K m_w + E_{ref} + E_{tra} \quad (6)$$

The latent heat of the orange samples is calculated using Eq. 7 (Abdelmotaleb *et al.* 2009).

$$\frac{\lambda_K}{\lambda_{wf}} = 1 + 23\exp(-40M_t) \quad (7)$$

The latent heat of free water evaporation was calculated according to using Eq. 8 (Darvishi 2017).

$$\lambda_{wf} = 2503 - 2.386(T - 273) \quad (8)$$

The thermal capacity is a function of the moisture content and can be calculated through Eq. 9 (Brooker et al. 1992).

$$C_P = 840 + 3350 \times \left(\frac{M_t}{1 + M_t}\right) \quad (9)$$

The thermal efficiency of the dryer is calculated using Eq. 10 (Soysal *et al.* 2006).

$$\eta_{en} = \frac{energy\ absorption}{P_{in} \times t} \quad (10)$$

The specific energy loss was measured using Eq. 11 (Darvishi *et al.* 2014)

$$E_{loss} = \frac{E_{in} - E_{abs}}{m_w} \ or\ E_{loss} = (1 - \eta_{en}) \times \frac{P_{in} \times t}{m_w} \quad (11)$$

Exergy analysis

With the onset of the energy crisis, energy and exergy (the maximum useful work that comes from a certain amount of available energy or from the flow of materials) analyses are among the leading thermodynamic research works. In the exergy analysis, the main purpose is to determine the location and amount of irreversible production during the various processes of the thermodynamic cycle and the factors affecting the production of this irreversibility. In this way, in addition to evaluating the performance of various components of the thermodynamic cycle, methods to increase cycle efficiency are also identified (Mokhtarian *et al.* 2016).

The general exergy equilibrium in the microwave chamber is as follows (Darvishi *et al.* 2016).

The amount of exergy transmitted due to evaporation in the drying chamber was calculated using Eq. 14 (Sarker *et al.* 2015)

$$ex'_{exap} = \left(1 - \frac{T_0}{T_p}\right) \times m_{wv}\lambda_{wp} \quad (14)$$

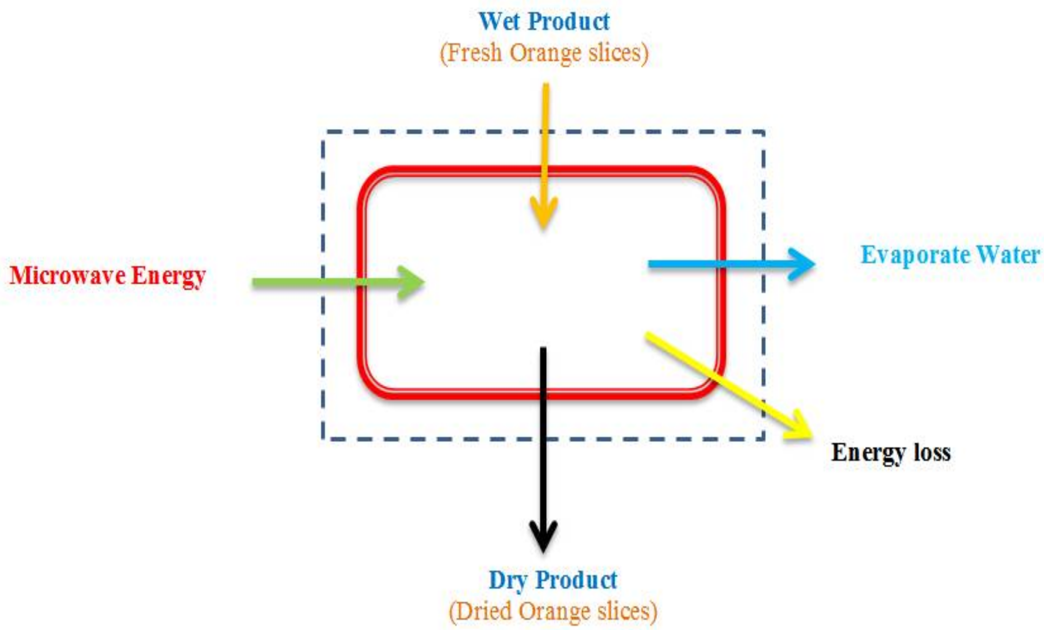

Fig. 3. Volume control of microwave system

$$EX_{in} = EX_{abs} + \underbrace{EX_{ref} + EX_{tra}}_{\text{Exergy loss}} \quad (12)$$

$$P_{in} \times t = \left(\left((m \times ex)_{dp} - (m \times ex)_{wp}\right) + ex'_{exap} \times t\right) + E_{ref} + E_{tra} \quad (13)$$

where m_{wv} is calculated using Eq. 15 (Darvishi *et al*. 2016).

$$m_{wv} = \frac{m_{t+\Delta t} + m_{wv}\lambda_{wp}}{\Delta t} \quad (15)$$

Specific exergy loss was calculated using Eq. 16 (Darvishi *et al*. 2014):

$$ex = C_p[(T - T_0) - T_0 \ln(\frac{T}{T_0})] \quad (16)$$

Exergy efficiency for each dryer system – as the exergy rate used in drying the product to the exergy of drying source supplied to the system is calculated by Eq. 17 (Dincer and Sahin 2004)

$$\eta_{en} = \frac{exergy\ absorption}{P_{in} \times t} \times 100 \quad (17)$$

The specific exergy loss was calculated using Eq. 18 (H Darvishi 2017).

In this research, the source of temperature and pressure in the environment was set at 20°C and 101.3 MPa, respectively.

$$EX_{loss} = \frac{EX_{in} - EX_{abs}}{m_w} \quad (18)$$

Statistical analysis

The orange slices were dried in microwave at three powers of 90, 360, and 900, three ohmic times of 3, 5, and 7 min and three voltage 30, 50 and 70 V and the ohmic results were sorted and calculated using the Excel software. All experiments were performed in triplicate and the results were analyzed using a factorial experiment in a completely randomized design with SAS statistical software.

Results and discussion

The analysis of variance (ANOVA) results of orange slices drying in different microwave powers for energy efficiency, specific energy loss, specific exergy loss, and exergy efficiency are shown in Table 1. According to the results, the power of the microwave, voltage and ohmic time were significant for energy efficiency, specific energy loss, specific exergy loss, and exergy efficiency at 1% level. The interaction effect (ohmic time × microwave power) of energy efficiency specific energy loss and exergy efficiency are significant at the 1% level and the interaction voltage × microwave power and voltage × ohmic time non-significance for energy efficiency, specific energy loss, specific exergy loss, and exergy efficiency. Thus, we compared the means with the LSD test.

Table 1. ANOVA results of energy efficiency, specific energy loss, specific exergy loss, and exergy efficiency under different powers and ohmic

Parameter		Energy efficiency		Specific energy loss	
	DF	Mean Square	F Value	Mean Square	F Value
Voltage	2	82.517	58.12**	11.07	40**
Ohmic time	2	2293.96	161.60**	190.190	687.09**
Microwave power	2	1987.01	139.42**	6.456	23.32**
Voltage* Ohmic time	4	0.847	0.60	3.749	13.54**
Voltage* Microwave power	4	1.550	1.09	0.763	2.75*
Ohmic time* Microwave power	4	69.186	48.73**	1.142	4.13**
ERROR	80	1.419		0.276	
Parameter		**Exergy efficiency**		**Specific exergy loss**	
	DF	**Mean Square**	**Mean Square**	**Mean Square**	**F Value**
Voltage	2	28.466	14.60	14.60	40**
Ohmic time	2	1385.91	95.76	95.76	687.09**
Microwave power	2	1367.91	70.13	70.13	23.32**
Voltage* Ohmic time	4	0.295	0.247	0.247	13.54**
Voltage* Microwave power	4	0.238	0.239	0.239	2.75*
Ohmic time* Microwave power	4	70.313	0.695	0.695	4.13**
ERROR	80	1.416		0.299	

The effect of power and ohmic time on energy efficiency

Based on Table 1, an interaction effect of microwave power and ohmic time on energy efficiency are significant at the level of 1%. Fig. 4 shows the interaction of these parameters on energy efficiency. According to the results obtained, energy efficiency increased significantly with increasing the power of the microwave and ohmic time. The maximum amount of energy efficiency is observed at the power of 90 W and ohmic time of 7 min (59.041%) and the minimum amount of energy efficiency is observed in a power of 90 W and ohmic time of 3 min (20.096%). Moreover, it can be stated according to the obtained results that the increase in the pretreatment time causes product mass reduction leading to an increase in the dry matter amount and dewatering of the orange slices. Product moisture reduction provides for shorter drying periods that can per se increase the energy output duration. Another reason for such a finding can be realized in orange slices' hardness reduction using ohmic pretreatment and such a reduction in hardness results in the readier de-moisturizing of the orange slices. In addition, the product dewatering takes a faster pace in higher powers and a larger deal of water is seminally forced out of the orange specimens and this causes the shortening of the drying period. In fact, according to the energy formula, it can be stated that the amount of energy absorbed in higher powers exceeds the amount of energy wasted and this makes the energy output be augmented.

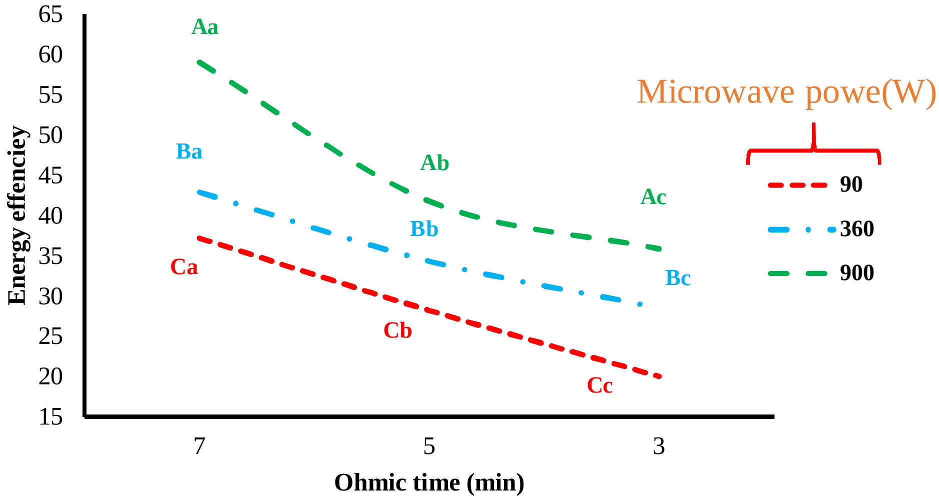

Fig. 4. Interaction of ohmic Pre-treatment and microwave power on energy efficiency
Similar capital letters represent non-significance in a same ohmic time, and similar small letters represent the non-significance in a same power.

According to figure (5), the increase in the voltage rate causes an increase in energy efficiency, as well. The highest energy efficiency was found in 70V and the lowest rate of energy efficiency was documented in 30V. There was evidence a significant difference between the effects of the various measured voltages on energy efficiency. The reason for this can be justified by the fact that increasing the voltage increases the sample temperature and hence the evaporation rate will occur faster and faster in the sample which results in less water after pretreatment, which causes the amount of energy efficiency has increased.

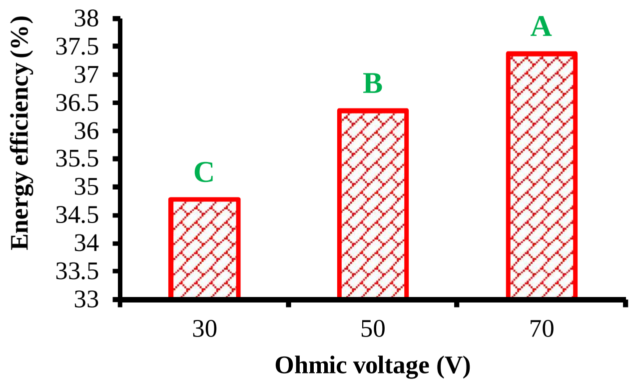

Fig. 5. The effect of ohmic voltage on energy efficiency

The effect of power and ohmic time specific energy loss

Based on Table 1, the power of the microwave was significant at 1% probability level. Fig. 6 shows the results obtained. The maximum amount of the specific energy loss is observed at the power of 90 W and ohmic time of 3 min (7.706 MJ) and the minimum amount of specific energy loss is observed in power of 900 W and ohmic time of 7 min (2.52 MJ). Since there is an inverse relationship between the specific energy loss and the product dewatering, the increase in the amount of water forced out of the product causes a reduction in the amount of specific energy loss. Furthermore, the change in the resistance to the dispersion of the moisture inside the orange slices causes a reduction in the drying time via changing the microstructure thereof subject to physical damage and this ends in a greater reduction in the amount of specific energy loss (Orikasa *et al.* 2018). Also, the voltage increasing caused the energy efficiency increasing, and with this increase, the amount of energy lost in drying decreases, which this reduction had the inverse relation of specific energy efficiency and specific energy loss.

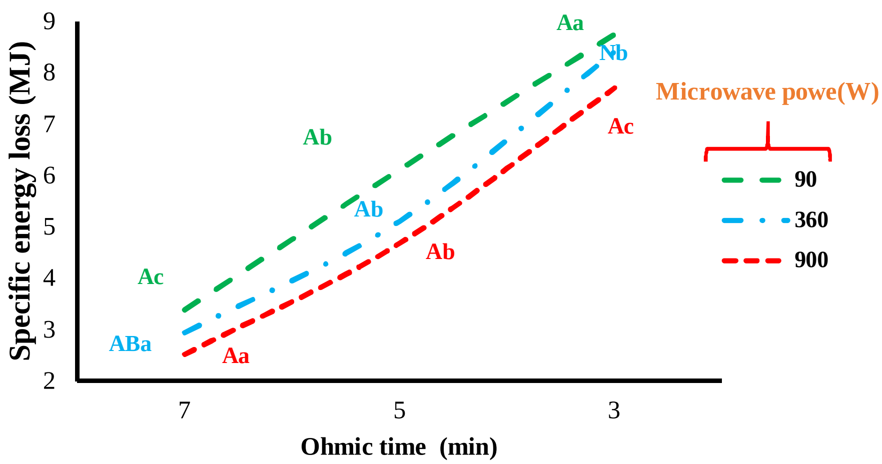

Fig. 6. Interaction of ohmic Pre-treatment and microwave power on specific energy loss
Similar capital letters represent non-significance in a same ohmic time, and similar small letters represent the non-significance in a same power.

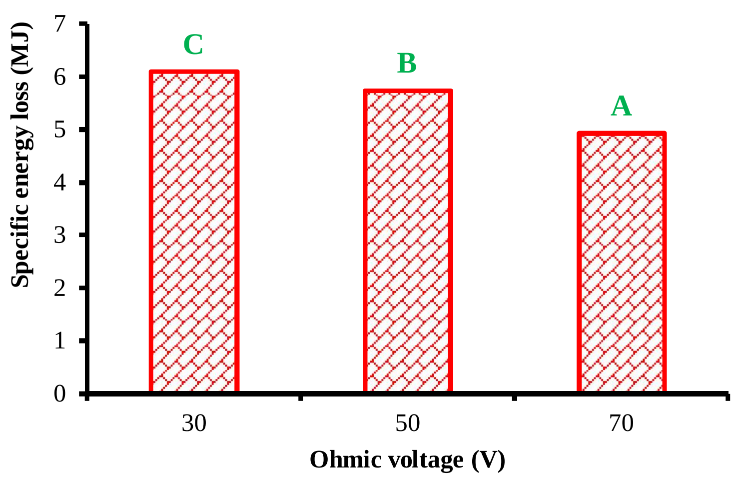

Fig. 7. The effect of ohmic voltage on specific energy loss

The effect of power and ohmic time on exergy efficiency

Figure 8 shows the interaction of these parameters on exergy efficiency. According to the results obtained, exergy efficiency increased significantly with increasing microwave power and ohmic time. The maximum amount of the exergy efficiency was observed at the power of 900 W and 7 min (47.76%) and the minimum amount exergy efficiency is observed in power of 360 W and 3 min (17.55 %). This result can be explained by the fact as power increases, the temperature of the microwave chamber dryer also increases and the product mass is removed faster, leading to reduced orange drying time. This reduction in time and faster mass removal, finally, increases the exergy efficiency of the microwave dryer. For exergy efficiency, useful power is highly important and by reducing drying time, the useful power increases. Moreover, according to Fig. 9, the ohmic time of oranges has a significant effect on the exergy efficiency. Based on this figure, with increasing the ohmic time, the amount of exergy efficiency increased, indicating a better heat exchange at higher ohmic times.

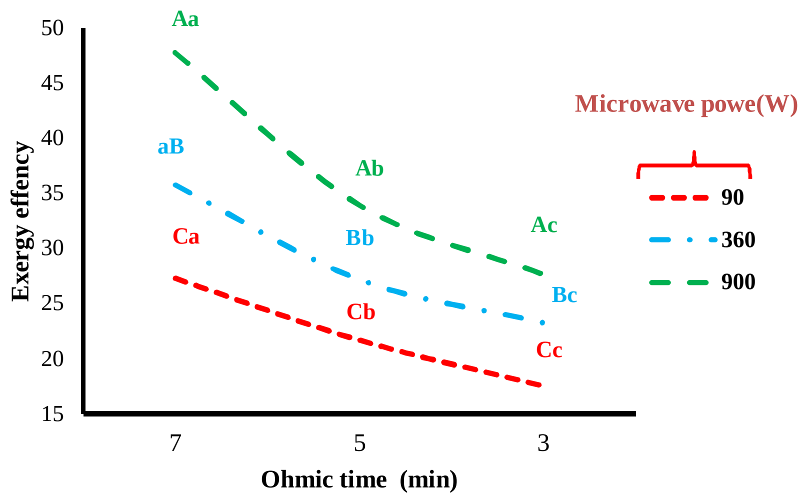

Fig. 8. Interaction of ohmic pre-treatment and microwave power on exergy efficiency
similar capital letters represent non-significance in a same ohmic time, and similar small letters represent the non-significance in a same power.

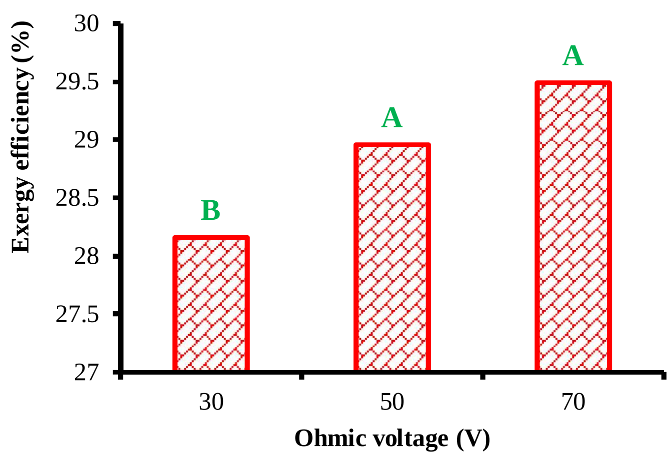

Fig. 9. The effect of ohmic voltage on Exergy efficiency

Effect of microwave power, ohmic time and ohmic voltage on Specific exergy loss

Figure 10 shows the results obtained. The maximum amount of the specific exergy loss is observed at the power of 90 W (11.648 MJ) and the minimum amount of specific exergy loss is observed in power of 900 W (8.421 MJ). Also, according to the figure, there is a significant difference between 90, 360 and 900 W. Also the maximum amount of the specific energy loss in ohmic time is observed at the time of 3 min (8.928 MJ) and the minimum amount of specific energy loss is observed in the time of 7 min (2.93 MJ). The maximum amount of the specific exergy loss is observed at the power of 30 V (10.624 MJ) and the minimum amount of specific exergy loss is observed in the power of 70 V (9.251MJ). The reason for this could be stated as follows that, ohmic pre-treatment has softened the fruit tissue than other pre-treatment methods that this also reduces the drying time and the easier absorption of temperature for the fruit. According to the results for ohmic process time and Specific exergy loss, can be stated that increasing the ohmic process time leads to more moisture removal, which results in faster removal of moisture in the dryer and thus do more and better work on the sample and reduce the amount of Specific exergy loss. On the other hand, increased drying power leads that faster energy being transferred to the sample to raise the temperature, which reduces specific exergy loss.

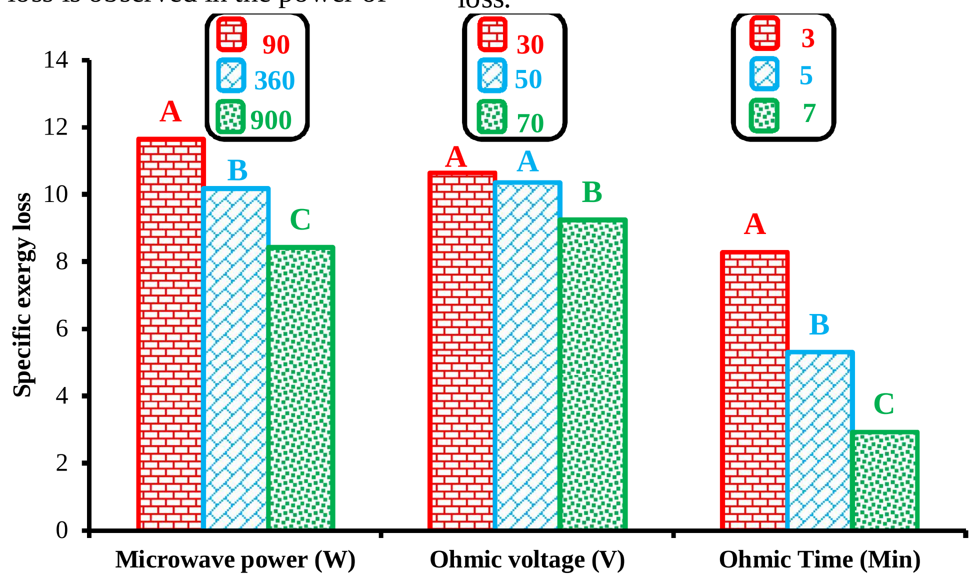

Fig. 10. Effect of microwave power, ohmic time and ohmic voltage on Specific exergy loss

Conclusion

Based on the obtained results, microwave power, ohmic time and ohmic voltage for the energy efficiency, specific energy loss, exergy efficiency and specific exergy loss have had the most significant effects. The interaction of ohmic time and microwave power on the energy efficiency, specific energy loss and exergy efficiency were only found significant. According to the results, the increase in ohmic and voltage time and microwave power brings about an increase in the energy and exergy efficiency and the increase in these factors causes reductions in the specific energy loss and specific exergy loss.

References

Abdelmotaleb, A., El-Kholy, M. M., Abou-El-Hana, N. H., & Younis, M. A. (2009). Thin layer drying of garlic slices using convection and combined (convection - infrared) heating modes. *Misr Journal of Agricultural Engineering* 26: 251–281.

Azadbakht, M., Torshizi, M. V., Ziaratban, A., & Aghili, H. (2017). Energy and exergy analyses during eggplant drying in a fluidized bed dryer. *International Agricultural Engineering Journal* 19(3): 177–182.

Azadbakht, M., Vehedi Torshizi, M., Aghili, H., & Ziaratban, A. (2018). Application of artificial neural network (ann) in drying kinetics analysis for potato cubes. *Carpathian Journal Of Food Science And Technology* 10(2): 96–106.

Brooker, D. B., Bakker-Arkema, F. W., & Hall, W. (1992). Drying and storage of grains and oilseeds. Van Nostrand Reinhold, publisher Springer US.

Darvishi, H. (2017). quality, performance analysis, mass transfer parameters and modeling of drying kinetics of soybean. *Brazilian Journal of Chemical Engineering* 34(1): 143–158.

Darvishi, H., Zarein, M., & Farhudi, Z. (2016). Energetic and exergetic performance analysis and modeling of drying kinetics of kiwi slices. *Journal of Food Science and Technology* 53(5): 2317–2333.

Darvishi, H., Zarein, M., Minaei, S., & Khafajeh, H. (2014). Exergy and energy analysis, drying kinetics and mathematical modeling of white mulberry drying process. *International Journal of Food Engineering*, 10(2), 269–280. doi:10.1515/ijfe-2013-0065

Deshmukh, A. W., Varma, M. N., Yoo, C. K., & Wasewar, K. L. (2013). Effect of ethyl oleate pretreatment on drying of ginger: Characteristics and mathematical modelling. *Journal of Chemistry* :1-6.

Dincer, I. (2000). Thermodynamics , Exergy and Environmental Impact. *Energy Sources* 22: 723–732.

Dincer, I. (2002). On energetic , exergetic and environmental aspects of drying systems S, .International Journal of Energy research 727: 717–727.

Dincer, I., & Sahin, A. Z. (2004). A new model for thermodynamic analysis of a drying process. *International Journal of Heat and Mass Transfer* 47(4): 645–652.

Jindarat, W., Rattanadecho, P., & Vongpradubchai, S. (2011). Analysis of energy consumption in microwave and convective drying process of multi-layered porous material inside a rectangular wave guide. *Experimental Thermal and Fluid Science* 35(4): 728–737.

Min, Z., Chunli, L., & Xiaolin, D. (2005). Effects of Heating Conditions on the Thermal Denaturation of White Mushroom Suitable for Dehydration. *Drying Technology* 23(5): 1119–1125.

Mokhtarian, M., Tavakolipour, H., & Kalbasi-Ashtari, A. (2016). Energy and exergy analysis in solar drying of pistachio with air recycling system. *Drying Technology*, 34(12), 1484–1500.

Nouroallahi Soghani, B., Azadbakht, M., & Darvishi, H. (2018). Ohmic blanching of white mushroom and its pretreatment during microwave drying. *Heat and Mass Transfer* 54 (12): pp 3715–3725.

Orikasa, T., Ono, N., & Watanabe, T. (2018). Impact of blanching pretreatment on the drying rate and energy consumption during far-infrared drying of Paprika (*Capsicum annuum* L .), *Food Quality and Safety* 2(2).

Salengke, S., & Sastry, S. K. (2005). An Effect of Ohmic Pretreatment on the Drying Rate of Grapes and Adsorption Isotherm of Raisins. *Drying Technology* 23: 37–41.

Sarker, M. S. H., Ibrahim, M. N., Abdul Aziz, N., & Punan, M. S. (2015). Energy and exergy analysis of industrial fluidized bed drying of paddy. *Energy* 84:131–138.

Sharma, G. P., & Prasad, S. (2006). Specific energy consumption in microwave drying of garlic cloves. *Energy* 31(12): 1585–1590.

Soysal, Y., Öztekin, S., & Eren, Ö. (2006). Microwave Drying of Parsley: Modelling, Kinetics, and Energy Aspects. *Biosystems Engineering* 93(4): 403–413.

Wray, D., & Ramaswamy, H. S. (2015). Novel Concepts in Microwave Drying of Foods. *Drying Technology* 33(7): 769–783.

Yogendrasasidhar, D., & Pydi Setty, Y. (2018). Drying kinetics, exergy and energy analyses of Kodo millet grains and Fenugreek seeds using wall heated fluidized bed dryer. *Energy* 151: 799–811.

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آنالیز انرژی و اکسرژی در خشک کردن ورقه‌های پرتقال با روش اهمیک

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چکیده

در این تحقیق آنالیز انرژی و اکسرژی در خشک‌کن ماکروویو برای خشک کردن برش‌های پرتقال بررسی شده است که برای این تحقیق ابتدا پرتقال‌ها به‌صورت برش‌های با ضخامت 4 میلی‌متر بریده شده سپس با روش اهمیک در زمان‌های پیش تیمار 3، 5 و 7 دقیقه در ولتاژهای ۳۰،۵۰ و 70 ولت تحت پیش تیمار اهمیک قرار گرفتند. سپس نمونه‌ها در سه تکرار با استفاده از خشک‌کن ماکروویو در سه توان 90، 360 و 900 وات خشک شدند. آنالیزهای آماری نشان داد که زمان اهمیک، ولتاژ اهمیک و توان ماکروویو برای بازده انرژی و اکسرژی و اکسررژی و انرژی تلف شده در سطح آماری 1 درصد معنی‌دار شده است. بیشترین مقدار بازده انرژی و اکسرژی در توان 900 وات و در زمان اهمیک 7 دقیقه مشاهده شد که به‌ترتیب 59/041 و 47/76 درصد بوده است. بیشترین مقدار انرژی تلف شده در توان 90 وات و زمان 3 دقیقه بود. توان ماکروویو، زمان اهمیک و ولتاز اهمیک همگی از لحاظ آماری برای پارامترهای (انرژی و اکسرژی) معنی‌دار بودند و با افزایش مقدار مقدار بازده انرژی و اکسرژی زیاد شد در حالی که انرژی و اکسرژی تلف شده کاهش یافت.

واژه‌های کلیدی: ماکروویو، پرتقال، پیش تیمار اهمیک، انرژی و اکسرژی

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Research Full Papers

Mineral composition, bioactive compounds and antioxidant activity of *Salvia hispanica* L as affected by thermal and non-thermal treatments

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Abstract

In this study, the effect of thermal treatments (roasting and autoclave) and non-thermal treatments (soaking and germination) on total phenolic content, total flavonoid content, antioxidant activity and bioavailability of minerals of chia seed was evaluated. Results showed thermal treatments increased the total phenolic content in samples such that the total phenolic content increased from 0.95± 0.1 mg (GAE/g) (control sample) to 1.32± 0.12 mg (GAE/g) (roasted sample) and 1.11± 0.1 mg (GAE/g) (autoclaved sample). Soaking reduced the total phenolic content in samples while germination increased the amount of total phenolic content in the samples. Using the roasting treatment had no significant impact on the total flavonoid content of samples, while using the autoclave, soaking and germination treatments reduced the total flavonoid content of samples. Roasting and autoclaving increased the antioxidant activity of samples while soaking reduces the amount of antioxidant activity among the samples and germination had no considerable effect on the antioxidant activity of samples. Moreover, germination treatment increased the macro and micro elements of minerals in samples. Thermal treatment (roasting) had no significant impact on the amount of minerals and only increased the Fe^{2+} in samples. FTIR Spectra showed thermal treatment reduced the amount of polysaccharide (1740 -1750 cm^{-1}) and protein /lipid (2800-3000 cm^{-1}) in samples.

Keywords: Chia seed; Total phenolic content; Total flavonoid content; FTIR.

Introduction

Chia seed, scientifically called *Salvia hispanica* L, is a one-year-old plant belonging to the *Lamiaceae* family which grows naturally in the Central America. Chia seed is widely used in breakfast cereal, cookies snacks, juices, cakes and yoghurt all over the world including Canada, Chile, Australia, New Zealand and Mexico(Amato *et al*. 2015). Chia seed has a lot of antioxidant compounds like chlorogenic acid, caffeic acid, myricetin, quercetin and minerals such as calcium, magnesium, potassium and iron (Barreto *et al*. 2016; Mohd Ali *et* al. 2012; Ullah *et al*. 2016). It is many years that thermal treatments such as autoclave, roasting ad microwave as well as the non-thermal treatments such as germination and soaking are used to improve the performance and nutritional properties of grains(Gómez-Favela *et al*. 2017; Yadav *et* al. 2018). Roasting is a high temperature (150– 400^0C) and short-term process which plays a critical role in creating the color, desirable taste and flavor as well as improving the nutritional value of grains together with various chemical reactions (Chandrasekara and Shahidi 2011). Jannat et al. (2010) investigated the impact of roasting conditions on the antioxidant properties and total phenol in 8 varieties of sesame. Results of this study revealed that as the roasting temperature increases, the antioxidant properties and total phenol increase in samples.

Soaking is a preliminary stage before cooking which makes the texture soft and reduces the cooking time (Xu and Chang, 2008; Yadav *et al*., 2018). While the germination is an inexpensive process starting with water absorption and ending with rooting out. During the germination process, the metabolism

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activities leads to hydrolysis of protein, carbohydrate and synthesis and aggregation of metabolites which improve the nutritional properties (Gómez-Favela *et al*., 2017). Chinma *et al.* (2015) investigated the impact of germination on the nutritional properties of rice flour. Results of this study revealed that germination for 48 (h) increases the amount of protein, magnesium, phosphorus, potassium and antioxidant properties and increases the phytic acid and total starch of rice flour (Chinma *et al.*, 2015).

According to conducted studies, there has been no research on the effects of thermal and non-thermal treatment on Chia seeds. Therefore, the present research investigated the effects of thermal treatment (autoclave and roasting) and non-thermal (germination and soaking) on the physicochemical properties of Chia seed.

Material and methods

Chia seed Argentinean was purchased from the local farmer's market in Mazandaran province of Iran. For the analytical test, chemicals were purchased from Merck, Darmstadt, Germany.

Roasting

The electric oven was used to study the impact of temperature (165℃) and time (30 min) of roasting on physicochemical properties of Chia seed.

Autoclave

Distilled water was added to chia seed in the ratio of 1:10(w/v) and autoclaved for 20 min at 121ºC and 15 psi. Then, the samples were dried by freeze- dried.

Soaking

At ambient temperature, chia seed were soaked in the water (1:4 (w/v)) for 12 h, and the excess water was removed. Then, the samples were freeze dried.

Germination

For sterilization, chia seed was immersed in a sodium hypochlorite solution (5% (w/v)) in the ratio of 1:10 (w/v) for 2 min and then, washed the chia seeds twice with distilled water. The chia seeds were germinated for 7 days at 25ºC until sprouting formed. Then, the samples were dried by freeze dried.

Before performing the test, a laboratory mill was used to mill raw chia seed and chia seed then were treated (autoclave, roasting, germination and soaking) and sieved to get average particle size of < 250 µm.

Total phenolic content

At ambient temperature, 0.2 (g) defatted sample was incorporated with 4 ml ethanol: water: HCl (80: 19: 1 ratio) for 2 h. Then, the mixture was centrifuged at 2000 (g) for 15 min. 0.2 supernatant was incorporated with of folin ciocalteous reagent and sodium carbonate (10%). At a wavelength of 760 nm, the absorption of samples was evaluated. The total phenolic content in the samples was expressed on the basis of Gallic acid (mg GAE/g) (Jogihalli *et al*., 2017).

Phenolic compounds

The HPLC (smart line, Knauer, Germany) equipped with PDA detector was used to analyze separate phenolic compounds in the chia seed. The acetic acid (5%) in water at flow rate of 1ml/ min was used as mobile phase. The injection volume was 20µl at 30ºC. The absorbance of the samples was measured at 330 nm.

DPPH Assay

At ambient temperature, 1(g) sample was incorporated with 10 ml ethanol: water: HCl (80: 19: 1 ratio) for 2 h. The mixture was placed at 40 (°C) for 4 h. For 20 min, the mixture was centrifuged at 3000×g. The DPPH was added to supernatant and the absorption of samples was evaluated at a wavelength of 515 nm (Beta *et al*., 2005; Yu and Nanguet 2013) . The percentage of scavenging radical was calculated as followed (Eq.1)

$$\text{Scavenging radical (\%)} = \frac{\text{Abs}_{\text{Blank}} - \text{Abs}_{\text{Sample}}}{\text{Abs}_{\text{Blank}}} \quad (1)$$

Total Flavonoid content

1.25 ml of distilled water was incorporated with 0.25 ml of sample and 75 µl of 5% (w/v) sodium nitrite ($NaNO_2$). Then, 0.15 ml of 10% (w/v) aluminum trichloride solution, 0.5 ml 1M NaOH and 0.775 ml of distilled water was incorporated to mixture. At a wavelength of 510 nm, the absorption of samples was evaluated. The total flavonoid content in the samples was expressed on the basis of quercetin (g/Kg EQ dry sample) (Jogihalli *et al*., 2017).

Mineral composition

1 (g) of samples were heated at 200ºC for complete carbonization of the material. The samples were placed in a furnace at 550ºC for 5 h. After cooling the samples, 1 ml of nitric acid was added to them. After reagent removing, the samples were placed in the furnace at 550ºC to obtain white ashes. Then, 1 ml of HCL and 2 ml of MilliQ water ware incorporated to the ashes. To help solubilization, the samples were hated at 80ºC. An optical emission spectrometer via inductively coupled plasma (ICP-OES) (Perkin Elmer, Optima 8300) was used to evaluate macro and micro minerals (Barreto *et al.*, 2016).

FTIR

FTIR (Tensor, Burker, Germany) was used to investigate the effect of thermal and non-thermal treatment on chemical changes on chia seed in the range of 400 to 4000 cm^{-1} wavenumber (López *et al*., 2018).

Statistical analysis

Experiments were evaluated based on a completely randomized design. To compare the means and investigating the impacts of treatments, Duncan Multiple Range test was utilized. During all stages of statistical analysis, SPSS 19 was used for analysing the data. At least three repetitions were performed for each experiment.

Results and Discussions:

Total phenolic content

Impact of thermal treatment on the total phenol of chia seed is shown in table 1. Using the thermal treatments such as roasting and autoclave increases the total phenolic content in samples such that the total phenolic content increased from 0.95± 0.1 mg (GAE/g) (control sample) to 1.32± 0.12 mg (GAE/g) (roasted sample) and 1.11± 0.1 mg (GAE/g) (autoclaved sample). Applying the thermal treatment, due to breaking of the cellular matrix and better bonding of phenol compounds with pectin and cellular network and aggregation in seed shell increase the total phenol in samples (Chandrasekara and Shahidi, 2011). Table 1 shows the effect of non-thermal treatments on total phenolic content of samples. Soaking reduced the total phenol content in samples. After soaking, due to the water absorption by the seeds, phenolic compounds are transferred from seed to water due to leaching leading to the decreased total phenol content in samples. On the basis of results (Table 1), germination increased the phenol compounds in samples. During the germination process, due to the change in activity of enzymes involving in phenol compound synthesis as well as breaking of phenol compounds connections, the total phenolic content in samples is increased. The amount of change in phenol compounds depends on the cultivar type, culturing conditions, culturing time duration and extraction method (López-Amorós *et al*., 2006; Cáceres *et al*., 2014). Chandrasekara and Shahidi (2011) reported that roasting (130^0C for 33 min.) increases the amount of total phenol compounds in peanut. Xu and Chen (2008) reported that soaking process reduces the amount of total phenol compounds in pea and lentil grains.

Total Flavonoid content

Impact of thermal and non-thermal treatments on the total flavonoid content of all samples is shown in table 1. Based on the results, using the roasting treatment has no significant impact on the total flavonoid content of all samples, while using the autoclave treatment reduced the total flavonoid content of all samples. Heating the seeds under pressure makes the cellular wall softer and more breaking leading to the leaching of more flavonoid compounds from the seed. Also, since most flavonoid compounds are in the shell and water soluble, using the treatments of soaking and germination due to leaching of flavonoid compounds reduced the total flavonoids content in samples (Suh *et al.*, 2017; Yadav *et al*., 2018).

Antioxidant activity

The effect of thermal treatment on the antioxidant activity of chia seed is shown in table 1. Using the thermal treatments such as roasting and autoclaving increases the antioxidant activity of samples. Due to the thermal activities, phenol compounds, especially Tannins, form the insoluble complex with proteins in grain as a result of which, the phenol compounds remain inside the grain. Because of water evaporation during the process, concentration of phenol compounds in seed shell increases resulting to the increased antioxidant activity of samples. On the other hand, during the roasting process, the Maillard reaction and formation of melanoidins can increase the samples' antioxidant activity more (Perrone *et al*., 2012). Based on the results (Table 1), soaking reduces the amount of antioxidant activity among the samples which is likely due to the reduction of phenol compounds by leaching in samples, while the germination did not affect significantly the antioxidant activity of samples.

Table 1. Effect of thermal and non-thermal treatment of total phenolic content, total flavonoid content and antioxidant activity

Mineral contents	Control	Roasting	Germinate
Ca	22173± 80.34^{b}	22214± 65.2^{b}	28368± 90.7^{a}
Na	395±19.2^{b}	388±20.7^{b}	5028± 85.4^{a}
Cu	23±2.4^{a}	29± 2.8^{a}	27± 1.1^{a}
P	5201± 68.7^{a}	5003± 87.1^{a}	4940± 92.8^{a}
Fe	690± 10.58^{b}	816± 20.52^{a}	721± 18.97^{b}
Zn	63±1.4^{b}	60± 2.1^{b}	76± 2.7^{a}

Means followed by the same letters in columns, are not significantly different ($p<0.05$).

Mineral content

The effect of thermal (roasting) and non-thermal (germination) treatments on bioavailability of minerals was investigated. Results (Table 2) showed that the germination treatment has increased the macro and micro elements of minerals in samples. The increase of minerals is likely due to the increase in activity of phytate enzyme resulting in the hydrolysis of phytic acid. As an anti-nutritional factor, the phytic acid plays a critical role in chelating the minerals leading to the formation of insoluble complex. While, during the germination process, phytic acid is converted into the Inositol and Orthophosphate anions due to the activity of phytate enzyme. This causes the release of minerals (Sharma *et al.*, 2017); while the thermal treatment (roasting) had no significant impact on the amount of minerals and only increased the Fe^{2+} in samples.

Table 2. Effect of thermal and non-thermal treatment on the macro and micro elements of minerals (mg/100g) of chia seed

Treatment	Total phenolic content	Total flavonoid content	Antioxidant activity (%)
Control	0.95± 0.1^{c}	0.73± 0.07^{a}	15.38± 1.1^{c}
Roasting	1.32± 0.15^{a}	0.74± 0.05^{a}	26.90± 1.7^{a}
Soaking	0.5± 0.08^{d}	0.265± 0.01^{d}	6.28± 0.9^{d}
Germinate	1.13± 0.14^{b}	0.536± 0.08^{c}	15.37± 1.5^{c}
Autoclave	1.11± 0.1^{b}	0.668± 0.04^{b}	18.67± 1.2^{b}

Means followed by the same letters in rows are not significantly different ($p<0.05$).

FTIR

The following figures show the most important peaks of the FTIR spectrum in control, germination and roasted samples. Based on obtained data, the FTIR spectrum can be classified into 6 groups: 1) 3200-3600 cm^{-1},

2) 2800-3000 cm^{-1}, 3) 1800-2200 cm^{-1}, 4) 1600-1800 cm^{-1}, 5) 1500-1600cm^{-1}, and 6) 1200-1300 cm^{-1} (Fig 1) (Tulukcu *et al.*, 2019).

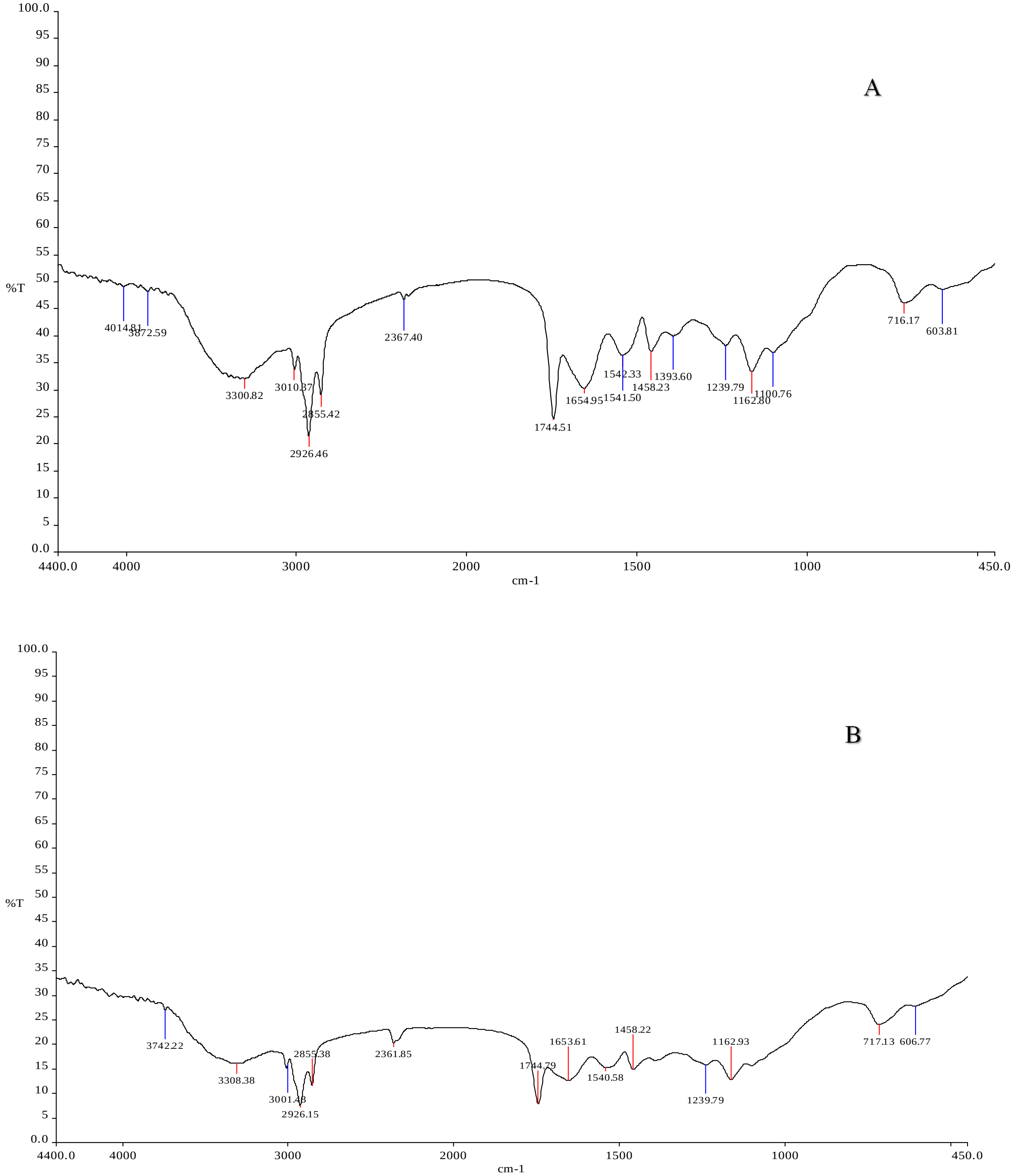

Fig 1. FTIR of (A) raw and (B) roasted of chia seed

Wave number range of 3200- 3600 cm^{-1} was due to hydroxyl groups (OH) of phenols and available N-H in amines II. The existence of peaks in the wave number range of 2800- 3000 cm^{-1} indicates the characteristic of stretching C-H bonding in Methyl groups. A peak with a centrality of 1748 cm^{-1} indicates the presence of stretching C=O bonding (Carbonyl) in esters of lipids and fatty acids in the sample. The existence of a peak in the range of 1220-1800 cm^{-1} indicates the stretching C=O bonding (Amide I) in samples. A peak in the range of 1500- 1600 cm^{-1} indicates the presence of stretching C=O bonding (Carboxylic group) probably due to the presence of Uronic acid in the sample structure. The observed peak in 1246 cm^{-1} is probably because of amide III in the structure. According to the comparison of FTIR Spectra of control and roasted samples, roasting reduced the amount of polysaccharide (1740 -1750 cm-1) and protein/ lipid (2800-3000 cm-1) in samples. However, the intensity and sharpness of peaks increased in 1500-1600 cm-1 and 1200- 1300 cm-1 indicating the effect of roasting on amounts of amides, amino acids, aldehydes and esters. The creation of melanoidins during the roasting process is probably the most important reason for changes in amounts and intensity of peaks in the FTIR spectrum.

Conclusion

This study evaluated different treatments on antioxidant and nutritional properties of chia seed. The results showed roasting improves functional properties (such as total phenolic content, antioxidant activity) of the chia seed. So, the modified chia seed is rich in total phenolic content and antioxidant activity and relieve good functional characterizes that could be used in food formulation like bread, sponge cake, muffins and etc.

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References

Amato, Mariana, Marisa C Caruso, Flavia Guzzo, Fernanda Galgano, Mauro Commisso, Rocco Bochicchio, Rosanna Labella, and Fabio Favati. 2015. 'Nutritional quality of seeds and leaf metabolites of Chia (S*alvia hispanica* L.) from Southern Italy', *European Food Research and Technology*, 241: 615-25.

Barreto, Aline D, Érika MR Gutierrez, Mauro R Silva, Fabiano O Silva, Nilton OC Silva, Inayara CA Lacerda, Renata A Labanca, and Raquel LB Araújo. 2016. 'Characterization and Bioaccessibility of Minerals in Seeds of Salvia hispanica L', *American Journal of Plant Sciences*, 7: 2323.

Beta, Trust, Shin Nam, Jim E Dexter, and Harry D Sapirstein. 2005. 'Phenolic content and antioxidant activity of pearled wheat and roller-milled fractions', *Cereal Chemistry*, 82: 390-93.

Cáceres, Patricio J, Cristina Martínez-Villaluenga, Lourdes Amigo, and Juana Frias. 2014. 'Maximising the phytochemical content and antioxidant activity of Ecuadorian brown rice sprouts through optimal germination conditions', *Food chemistry*, 152: 407-14.

Chandrasekara, Neel, and Fereidoon Shahidi. 2011. 'Effect of roasting on phenolic content and antioxidant activities of whole cashew nuts, kernels, and testa', *Journal of Agricultural and Food Chemistry*, 59: 5006-14.

Chinma, Chiemela Enyinnaya, Julian Chukwuemeka Anuonye, Omotade Comfort Simon, Raliat Ozavize Ohiare, and Nahemiah Danbaba. 2015. 'Effect of germination on the physicochemical and antioxidant characteristics of rice flour from three rice varieties from Nigeria', *Food chemistry*, 185: 454-58.

Gómez-Favela, Mario Armando, Roberto Gutiérrez-Dorado, Edith Oliva Cuevas-Rodríguez, Vicente Adrián Canizalez-Román, Claudia del Rosario León-Sicairos, Jorge Milán-Carrillo, and Cuauhtémoc Reyes-Moreno. 2017. 'Improvement of chia seeds with antioxidant activity, GABA, essential amino acids, and dietary fiber by controlled germination bioprocess', *Plant foods for human nutrition*, 72: 345-52.

Jannat, B, M Oveisi, N Sadeghi, M Hajimahmoodi, M Behzad, E Choopankari, and A Behfar. 2010. 'Effects of roasting temperature and time on healthy nutraceuticals of antioxidants and total phenolic content in Iranian sesame seeds (*Sesamum indicum* l.)', *Journal of Environmental Health Science & Engineering*, 7: 97-102.

Jogihalli, Praveen, Lochan Singh, and Vijay Singh Sharanagat. 2017. 'Effect of microwave roasting parameters on functional and antioxidant properties of chickpea (Cicer arietinum)', *LWT-Food Science and Technology*, 79: 223-33.

López-Amorós, ML, T Hernández, and I Estrella. 2006. 'Effect of germination on legume phenolic compounds and their antioxidant activity', *Journal of Food Composition and Analysis*, 19: 277-83.

López, Débora Natalia, Romina Ingrassia, Pablo Busti, Julia Bonino, Juan Francisco Delgado, Jorge Wagner, Valeria Boeris, and Darío Spelzini. 2018. 'Structural characterization of protein isolates obtained from chia (Salvia hispanica L.) seeds', *LWT*, 90: 396-402.

Mohd Ali, Norlaily, Swee Keong Yeap, Wan Yong Ho, Boon Kee Beh, Sheau Wei Tan, and Soon Guan Tan. 2012. 'The promising future of chia, Salvia hispanica L', *BioMed Research International*, 2012.

Perrone, Daniel, Adriana Farah, and Carmen M Donangelo. 2012. 'Influence of coffee roasting on the incorporation of phenolic compounds into melanoidins and their relationship with antioxidant activity of the brew', *Journal of Agricultural and Food Chemistry*, 60: 4265-75.

Sharma, Seema, Dharmesh C Saxena, and Charanjit S Riar. 2017. 'Using combined optimization, GC–MS and analytical technique to analyze the germination effect on phenolics, dietary fibers, minerals and GABA contents of Kodo millet (*Paspalum scrobiculatum*)', *Food chemistry*, 233: 20-28.

Suh, Seokjin, Yeong Eun Kim, Han-Joo Yang, Sanghoon Ko, and Geun-Pyo Hong. 2017. 'Influence of autoclave treatment and enzymatic hydrolysis on the antioxidant activity of Opuntia ficus-indica fruit extract', *Food science and biotechnology*, 26: 581-90.

Tulukcu, Eray, Nur Cebi, and Osman Sagdic. 2019. 'Chemical Fingerprinting of Seeds of Some Salvia Species in Turkey by Using GC-MS and FTIR', *Foods*, 8: 118.

Ullah, Rahman, Muhammad Nadeem, Anjum Khalique, Muhammad Imran, Shahid Mehmood, Arshad Javid, and Jibran Hussain. 2016. 'Nutritional and therapeutic perspectives of Chia (Salvia hispanica L.): a review', *Journal of food science and technology*, 53: 1750-58.

Xu, Baojun, and Sam KC Chang. 2008. 'Effect of soaking, boiling, and steaming on total phenolic contentand antioxidant activities of cool season food legumes', *Food chemistry*, 110: 1-13.

Yadav, Neelam, Devinder Kaur, Ritika Malaviya, Monika Singh, Mahrukh Fatima, and Lovy Singh. 2018. 'Effect of thermal and non-thermal processing on antioxidant potential of cowpea seeds', *International journal of food properties*, 21: 437-51.

Yu, Lilei, and Anne-Laure Nanguet. 2013. 'Comparison of antioxidant properties of refined and whole wheat flour and bread', *Antioxidants*, 2: 370-83.

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تأثیر تیمار حرارتی و غیرحرارتی بر میزان مواد معدنی، ترکیبات فعال زیستی و فعالیت آنتی‌اکسیدانی دانه چیا (*Salvia hispanica* L)

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چکیده

در این پژوهش، اثر تیمارهای حرارتی (برشته کردن و اتوکلاو) و تیمارهای غیرحرارتی (خیساندن و جوانه‌زنی) بر میزان فنل کل، مقدار فلاونوئید کل، فعالیت آنتی‌اکسیدانی و میزان مواد معدنی دانه چیا بررسی شد. نتایج نشان داد که تیمارهای حرارتی باعث افزایش میزان فنل کل در نمونه ها شد به‌طوری که میزان فنل کل در نمونه‌ها از (mg (GAE/g 0/1 ±0/95 در نمونه شاهد تا (mg (GAE/g 0/12 ±1/32 در نمونه برشته شده و (mg (GAE/g 0/1± 1/11 در نمونه اتوکلاو شده، افزایش یافت. خیساندن سبب کاهش میزان ترکیبات فنلی کل در نمونه‌ها شد در حالی که جوانه زدن باعث افزایش میزان ترکیبات فنلی کل در نمونه‌ها شد. برشته کردن اثر معناداری بر میزان ترکیبات فلاونوئید کل در نمونه داشت در حالی که اتوکلاو کردن، خیساندن و جوانه‌زنی سبب کاهش میزان ترکیبات فلاونوئید کل در نمونه‌ها شد. تیمارهای حرارتی (برشته کردن و اتوکلاو کردن) سبب افزایش فعالیت آنتی‌اکسیدانی در نمونه‌ها شد در حالی که خیساندن سبب کاهش میزان فعالیت آنتی‌اکسیدانی نمونه ها شد و جوانه‌زنی اثر معناداری بر میزان فعالیت آنتی‌اکسیدانی نمونه‌ها نداشت. جوانه‌زنی باعث افزایش میزان مواد معدنی در نمونه‌ها شد در حالی که تیمار حرارتی (برشته کردن) اثر معناداری بر میزان مواد معدنی نداشت و تنها میزان آهن در نمونه‌ها افزایش یافت. طیف به‌دست آمده از FTIR نشان داد، تیمار حرارتی سبب کاهش مقدار پلی‌ساکارید ($1740-1750\ cm^{-1}$) و نسبت پروتئین/ لیپید ($2800-3000\ cm^{-1}$) در نمونه‌ها شد.

واژه‌های کلیدی: دانه چیا، میزان فنل کل، میزان فلانوئید کل، FTIR

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Research Full Papers

A new study on the quality, physical and sensory characteristics of cupcakes with *Althaea officinalis* mucilage

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Abstract

In this study, the functionality of *Althaea officinalis* mucilage (AOM) on cupcake quality and its potential use in retarding the staling process have been studied. For this purpose, the effects of different concentrations of AOM (0, 0.25, 0.5, and 1%) on some physical properties such as hardness and color and the sensory properties of cupcakes and their batter were determined. In general, the overall properties of cupcake were notably influenced by mucilage addition. The results demonstrated that the mucilage addition significantly ($p<0.05$) improved physical properties of cupcakes (moisture content, specific volume, and batter density and viscosity) compared with the control sample. Hardness during storage decreased significantly with the addition of mucilage. The results from the comparison of means for the color parameter, indicated that the lowest L* value and the highest L* of crust belonged to the control sample and those that featured 0.25 and 1% mucilage, respectively. The cakes with 0.75 and 1% mucilage obtained the highest scores of sensory analyses.

Keywords: *Althaea officinalis*; Sensory properties; Quality; Cupcake.

Introduction

Bakery products are a very significant part of the daily diet of consumers. Among them, cakes are particularly popular because of their favorable sensory properties, easy availability, and low cost.

High-quality cakes have numerous characteristics, including high volume, uniform crumb structure, softness, long shelf life and tolerance to staling (Gelinas *et al*., 1999). These characteristics mainly depend on various factors such as a balanced formula, the ingredients, aeration of cake batters, mixing conditions during batter preparation and process conditions. The quality of cake can be influenced by the addition of substances such as hydrocolloids that have an impact on these characteristics (Anderson *et al*., 1988).

Hydrocolloids have been widely applied in food production to improve food texture, delaying starch retrogradation, improve moisture retention, extend the shelf life and enhance the overall quality of the products during storage (Gomez *et al*., 2007). As gluten-substitutes (Kim and De Ruiter, 1968; Toufeili *et al*., 1994; Sahraiyan *et al*., 2014), antistaling agents in bread and cakes (Armero and Collar, 1996; Davidou *et al*., 1996; Schiraldi *et al*., 1996), fat replacement (Albert and Mittal, 2002; Shokri Busjin, 2004; Kalinga and Mishra, 2009; Song *et al*., 2017), and source of fiber (Apling *et al*., 1978), hydrocolloids are added to food products. The extensive use of hydrocolloids in foods has made the necessity to search for new natural sources of hydrocolloids with special functional properties and appropriate pricing, which can be applied instead of commercial gums (Koochaki and Hesarinezhad, 2017). One potential source of these natural hydrocolloids is *Althaea officinalis*.

A. officinalis, of the *Malvaceae* family, is one of the traditional medicinal plants especially for the treatment of cough and irritation of mucous membranes (Deters *et al.*, 2010). *Althaea officinalis*, also known as Khatmi in Iran, has many flowers. Studies

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have shown that an aqueous extract of *A. officinalis* flower has potential benefits in inflammation, gastric ulcer, and platelet aggregation with no visible adverse effects (Hage-Sleiman *et al.*, 2011; Mousavi *et al.*, 2019). Mucilage is a hydrocolloid, a complex polymer with the nature of carbohydrate having branched structures and soluble hydrophilic polysaccharides, which are thick, sticky substances (Naqvi *et al.*, 2011). AOM as a new source of hydrocolloid has interesting functional properties that enable it to be employed as a natural thickener, stabilizer, and anti-oxidant agent with high thermal tolerance for application in the food and pharmaceutical industries (Mousavi *et al.*, 2019). Previous studies have shown that AOM had high total carbohydrate content (75.01%) comprise a high amount of uronic acids (28.06%), revealing its strong polyelectrolyte nature and the relative number of acidic polysaccharides in the mucilage. It has been reported that the major monosaccharide of this mucilage was xylose (32.52%), together with substantial amounts of glucuronic acid (26.53%), mannose (10.83%), rhamnose (12.42%), arabinose (4.19%), galactose (5.84%), glucose (6.15%), and with traces of galacturonic acid (1.53%). Studies have also revealed that this mucilage has an interesting characteristic of scavenging DPPH (Mousavi *et al.*, 2019).

To the best of our knowledge, no systematic study has so far provided information on the application of this novel hydrocolloid in bakery products, particularly in the cupcake. Therefore, this study was undertaken to evaluate the impact of different concentrations (0%, 0.25%, 0.5%, and 1%) of AOM on the cupcake quality and consumer acceptance as a result of supplementation.

Materials and methods

Mucilage extraction

Marshmallow flowers were purchased from an herbal market in Mashhad, Iran. Extraction of mucilage from the dried flowers of *A. officinalis* was carried out by maceration process. The powders of dried flowers were soaked in distilled water (for 1 h, pH 6.63, 55°C, and water/powder ratio 80:1) (Mousavi *et al.*, 2019). The extracted solution was then filtered and dried in an oven at 50°C and finally the powder was milled, packed and kept at cool and dry condition. The dried mucilage was milled and passed through a 50 mesh sieve.

Cupcake preparation

The control cupcake formula was: 100% flour, 90% sugar, 65% egg, 65% milk, 50% sunflower oil, 0.2% vanillin, 1.11% sodium bicarbonate, 1.35% sodium acid pyrophosphate, and 0.2% mono-calcium phosphate (Lebesi and Tzia, 2011). Three different AOM levels were added to the cupcake formulae. Cake batter was prepared in a Kenwood mixer (Model KM 400, Kenwood, UK) using sugar batter method. The oil and the sugar were creamed in the mixer at 180 rpm (speed 4) during 10 min. Eggs were then added and mixed for 6 min at the same rotation. Vanillin was also added and mixed at speed 4 for 1 min. Flour, milk, and AOM were added and mixed at speed 2 (90 rpm) for 4 min. The required quantities of batter (30 g) were placed into fat-coated aluminum pans which have 35-mm diameter and 45-mm height. The samples were baked at 180 °C in a laboratory oven with air circulation (Noble, Model: KT-45XDRC) for 30 min. The oven trays were placed at the same level in the oven with the same number of cake pans per baking batch. The cooled cakes (at room temperature for 1 h) were packed in polyethylene bags before textural analyses (during 14 days) and sensory characteristics test (day 0).

Physical Profiles

The specific volume and density of the cupcake was evaluated by the canola displacement method (Hosseini Ghaboos *et al.*, 2018). It was averaged from four replications. The moisture content of the samples was determined in an oven at 105°C for 4 h (AOAC, method no. 934.06). The viscosity of the cake batter was measured using a rotational viscosimeter (Model RVDV-II^{+} pro, Brookfield Engineering, Inc., USA).

Immediately after mixing, 200 ml of cake batter was poured into a 200 ml beaker and the viscosity was determined. The apparent viscosity of cake batters at constant shear rate (45.6 s^{-1}) were studied using spindle SC4-31 at 25°C.

Color measurement

In order to survey the effect of mucilage addition on color changes of the cupcake samples, a computer vision system was applied. Sample illumination was reached by two fluorescent lights (10 W, 40 cm in length), which were located in a black box (0.5m×0.5m×0.5m). The crumb color determinations of the midsection of the cakes, dough color, and crust of cupcakes were obtained by a high-definition camera (Canon Powershot G1X, Tokyo, Japan) which was located vertically at a distance of 20 cm from the samples. Due to the computer vision system perceived color as RGB signals, which is device-dependent (Fernandez *et al*., 2005), the images were converted into L*a*b* units to ensure color reproducibility. In the L*a*b* space, the color perception is uniform and therefore the difference between two colors corresponds approximately to the color difference perceived by the human eye (Pedreschi *et al*., 2007). The L* (lightness/darkness that ranges from 0 to 100) of cupcakes were performed using Image J software version 1.42e, USA.

Textural characteristics

Hardness of cupcakes was evaluated after removing the crust from the samples (2× 2× 2 cm) using a texture analyzer (Instron, Model 1140, UK). Instron is equipped with a load cell (5 N) and cylindrical probe with a diameter of 24 mm. The force needed for 40% compression was documented under the following conditions: 50 mm/min probe speed, 1in sample thickness, and 5– 50 N of force exerted by the load cell device. According to F_{max}, the maximum compressive force exerted on the sample was reported. The hardness unit is based on Newton. By averaging four readings, the reported values were determined. The hardness of the samples was evaluated at 1, 7 and 14 days after cooking in order to evaluate the interactions between different percentages of mucilage and storage time on the produced cupcakes (Beikzadeh *et al.*, 2017).

Sensory evaluation

Sensory evaluation was assessed by a panel of 15 trained consumers using hedonic scales, scored 1–10, in which degree of liking were described (1= dislike extremely, 5= neither like nor dislike, 9= like extremely). The cupcake samples were placed on dishes and named with random 3-digit numbers (Lee *et al.*, 2008). Panelists evaluated the samples in a testing area and were instructed to rinse their mouths with water between samples to minimize any residual effect.

Results and discussion

Physical properties

The physical properties of cupcakes and batters containing different concentrations of mucilage are shown in Table 1. Moisture content is an important quality characteristic in baked products as its increase can improve the overall quality of the products during storage (Dadkhah *et al*., 2012).

The moisture content of cakes varied from 10.61 to 11.41%. Compared with the control, moisture contents were significantly higher in samples containing mucilage. With increase in concentrations of mucilage the moisture contents were increased, although the differences were statically insignificant ($p<0.05$). These results may be due to the hydrophilic property of the added hydrocolloid causing interaction between flour and water. The hydrogen bonding interaction between the hydroxyl groups of water and those of the mucilage lead to more water absorption (Friend *et al*., 1993; Oakenfull *et al*., 1999; McCarthy *et al*., 2005; Song *et al*., 2017).This feature of hydrocolloids depends on the type of hydrocolloid and its interactions with the other ingredients of formulation (Mousavi *et al.*, 2019).Our results coincide with the findings of Beikzadeh et al. (2018) when

Psyllium seed and xanthan gums were added to the sponge cakes (Samira Beikzadeh *et al.*, 2018). Sheikholeslami et al. (2017) also reported an increase in moisture content of sponge cake by increasing the amount of chubak extract and *Lallemantia royleana* seed gum as natural additives. Many researchers also obtained similar results with different gums (Ayoubi *et al.*, 2009; Gomez *et al.*, 2007; Shalini & Laxmi, 2007; Sidhu & Bawa, 2002; Tavakolipour & Kalbasi-Ashtari, 2007).

Table 1. Physical properties of cupcakes manufactured with and without (control) different concentration of AOM.

Concentration (%)	Physical properties			
	Apparent viscosity (Pa.s)	Moisture content (%)	Specific volume (cm^3/g)	Density of Batter (g/ml)
0.00	12.77±0.25[a]	10.61±0.10[a]	0.82±0.17[a]	1.13±0.10[a]
0.25	24.34±0.22[b]	11.25±0.14[b]	2.03±0.13[b]	1.16±0.11[a]
0.50	24.54±0.15[b]	11.38±0.15[b]	2.24±0.12[bc]	1.07±0.07[a]
1.00	37.69±0.20[c]	11.41±0.18[b]	2.41±0.10[c]	1.05±0.07[a]

Values are the average of triplicates ± standard deviation. For each characteristic, data followed by different letters are significantly ($P< 0.05$) different.

The density of batter samples varied from 1.13 to 1.05, but the differences among density of samples were statistically insignificant ($p>0.05$). Density indicates the amount of air incorporated in the dough (Allais *et al.,* 2006a); where it is inversely related to the air incorporation in the batter (Allais *et al*., 2006b; Gómez *et al.,* 2010). Ayoubi et al. (2009) reported that the addition of guar and xanthan gums to the cake reduced sample apparent density; whereas Gomez et al. (2007) showed that the presence of hydrocolloids reduced the amount of air retained on cake batter as demonstrated by the increase in its density.

The dough viscosity is an important quality property in cake influencing the volume of the cake. Evaluations with regard to apparent viscosity showed that it increased significantly, but the differences among 0.25 and 0.5% were not significant. This increasing trend can be directly related to the more air incorporated to the batter (Swami *et al.*, 2004). Swami et al. (2004) reported that an increase in water content or air incorporation level in the batter leads to a reduction in viscosity of batter samples. The batter with 1.00 % AOM powder exhibited the highest viscosity among all the cake batters. In the present study, the apparent viscosity of cake batters varied from 12.77 to 37.69 Pa.s (shear rate= 45.6 s^{-1}) depending on the concentration of AOM powder.

It is known that the specific volume of baked cake is an indicator of the air incorporation during mixing and retention during baking depending on batter viscosity and bubble distribution within the batter. A higher gas retention and higher expansion of the product leads to a higher specific volume (Gómez *et al*., 2008). As shown in Table1, the specific volumes of samples indicated a significantly higher value with increasing mucilage content showing a higher amount of air remained in the cake. Generally, with the increase in the amount of mucilage, the cake volume and batter viscosity were increased. These results are in disagreement with those found by Young and Bayfield (1963) who reported that the cake volume decreased when hydrocolloid was added.

The results obtained were in agreement with those obtained by Gomez et al. (2007) who found that the hydrocolloid addition lead to higher volumes. An improvement in the bread specific volume obtained when adding 0.5% HPMC and xanthan to wheat bread formulation (Rosell *et al.,* 2001). Similar results were found for cake by adding some other hydrocolloids (Miller and Hoseney, 1993; Gómez *et al*., 2008; Sowmya *et al*., 2009; Sheikholeslami et al., 2017; Beikzadeh *et al.*, 2018; Koocheki and Hesarinejad, 2019a,b).

Textural Properties

Figure 1 presents the influence of AOM on cupcake hardness during 1, 7 and 14 days post-baking. The hardness of the samples increased during storage. This increase was higher in the control sample and sample containing 0.25% mucilage. The addition of mucilage significantly decreased cake hardness compared to the control sample. With the increase in the mucilage percentage, hardness decreased excessively. As portrayed in Figure 1 the samples featuring 1% and 0.75% mucilage respectively had the lowest hardness that hardly changed during storage. The results obtained were in agreement with previous findings of Beikzadeh et al. (2017) who observed that the addition of 0.25% marve combined with 0.25% psyllium decreased cake hardness compared with the control sample. Similar results were reported by Hajmohammadi et al. (2014) and Ayoubi et al. (2008). Some researchers also reported the positive effect of different gums on making soft cake texture and reducing the staling during storage (Peighambardoust *et al*., 2016; Sheikholeslami *et al*., 2017; Beikzadeh *et al*., 2017). This softening effect should be attributed to mucilage water retention capacity (Rosell *et al*., 2001; Chaplin, 2003; Hug-Iten *et al*., 2003; Dikeman and Fahey, 2006), and a possible inhibition of the amylopectin retrogradation (Biliaderis *et al*., 1997; Collar *et al*., 2001). Davidou et al. (1996) reported that the addition of HPMC lead to soften the product texture because of the obstruction of interaction between the polymers of starch, and also protein with starch, by the chains of the gum, resulting in changes to hardness.

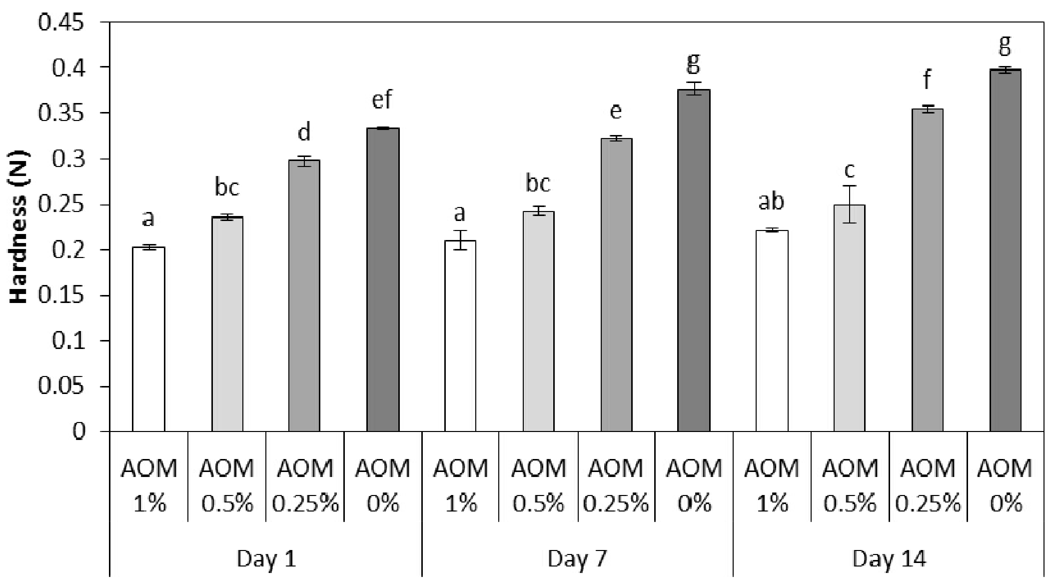

Fig. 1. Hardness of fresh and 14 days stored cupcakes containing different concentrations of AOM

Color measurement

Color is one of the most important characteristics affecting the appearance of the cake. The color of the crust is affected by the Millard reaction. Additionally, the color of crumbs is influenced by the ingredients in the formula (Akesowan, 2007). The effect of mucilage addition on color is shown in Table 2. The crumb of cupcakes showed a decrease in L* value as the amount of mucilage increased; however, the differences were insignificant. But the crust color was influenced by the amount of mucilage as indicated by change in L* values shown in

Table 2. Samples containing mucilage presented lighter crust color in comparison to the control sample. The L* values of the crust increased significantly. The darkest (the lowest L* value) and the lightest crust color (highest L*) were observed in the control sample and those that featured 0.25 and 1% mucilage, respectively. Increasing *L** value may be related to retention of moisture by the gums (Lazaridou *et al*., 2007). Retention of moisture during the baking process reduced the level of crust changes in bakery products. The lightening of cake was due to changes of crust. Uniform crust more than non-uniform crust enhanced L* value (Lazaridou *et al.*, 2007). Beikzadeh et al. (2017), Sadeghnia *et al.* (2011) and Sahraiyan *et al.* (2014) obtained the same results with this study.

Table 2. Lightness index (L*) of dough and cupcakes with different concentrations of AOM

Concentration (%)	Cake crumb	Cake crust	Cake dough
0.00	54.07±0.92[a]	57.70±1.12[c]	69.10±1.15[b]
0.25	52.01±0.98[a]	75.78±1.31[a]	63.66±1.52[b]
0.50	53.99±1.01[a]	69.09±0.85[b]	60.70±2.08[b]
1.00	52.32±0.55[a]	72.96±1.06[a]	62.34±2.08[b]

Sensory evaluation

Sensory attributes play important role in determining the acceptability of product (Hesarinejad *et al*., 2017, 2019). Therefore, the sensory evaluation of samples was evaluated in terms of odor, flavor, porosity, appearance, Hardness and overall acceptability (Table 2). In general, with the addition of mucilage, all sensory attributes except odor desirability were significantly ($P<0.05$) enhanced compared with the control sample. Attending the odor desirability, Sensorial evaluation shows that there is not any significant difference among samples ($P<0.05$). But larger percentage of mucilage leads to a higher evaluation of porosity, appearance, flavor, Hardness and overall acceptability and the highest acceptance score was obtained when 0.5 and 1 % mucilage was added. The presence of gums increases acceptability relating to moisture retention, texture, softness and flavor (Bench, 2007). The improving effect of different gums addition on the texture of cake has been reported previously by other researchers (Gomez *et al.*, 2007; Sowmya *et al*., 2009; Hajmohammadi *et al*., 2014; Beikzadeh *et al*., 2018).

Table 3. Sensory evaluation of cupcakes containing different concentrations of AOM

Concentration (%)	Crumb color lightness	Odor desirability	Porosity	Appearance	Flavor	Texture	Total acceptance
0.00	8.3±1.2[b]	7.4±1.0[a]	6.1±0.9[a]	6.1±1.0[a]	6.0±0.7[a]	5.7±1.0[a]	6.5±1.1[a]
0.25	7.3±1.0[a]	7.6±1.1[a]	6.9±0.8[ab]	7.0±1.1[b]	7.1±1.1[b]	6.1±0.8[ab]	6.9±0.9[ab]
0.50	7.8±1.1[a]	7.3±1.0[a]	7.6±1.0[bc]	7.3±0.9[b]	7.3±0.9[b]	6.5±0.8[b]	7.5±1.2[b]
1.00	7.5±1.2[a]	7.2±1.3[a]	8.0±0.09[c]	7.4±0.9[b]	7.4±1.0[b]	6.8±1.0[b]	7.6±0.9[b]

Nine-point hedonic scale with representing extremely dislike, neither like nor dislike, and extremely like.

Conclusion

This study showed that AOM does not have any undesirable effect on the physical and sensory properties of cupcakes. Moreover, results of the evaluations showed that the addition of mucilage improves physical properties without altering sensory properties of cakes. The highest viscosity, moisture content and specific volume was related to samples containing 1% mucilage. Presence of mucilage decreased cake hardness compared with the control sample. The results indicated that the addition of mucilage to the cupcake increased shelf-life. The results also showed that adding AOM increased the lightness of cupcake's crust. In conclusion, it is possible to take advantage of this mucilage to improve physical and sensory properties of foods such as cupcake. Further studies are recommended to determine the applicability of this novel additive in other bakery products.

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References

Akesowan, A. (2007). Effect of a konjac flour/soy protein isolate mixture on reduced-fat, added water chiffon cakes. *AU Journal of Technology*, *11*(1), 23-27.

Albert, S., & Mittal, G. S. (2002). Comparative evaluation of edible coatings to reduce fat uptake in a deep-fried cereal product. *Food Research International*, *35*(5), 445-458.

Allais, I., Edoura-Gaena, R. B., & Dufour, É. (2006b). Characterisation of lady finger batters and biscuits by fluorescence spectroscopy—Relation with density, color and texture. *Journal of food engineering*, *77*(4), 896-909.

Allais, I., Edoura-Gaena, R. B., Gros, J. B., & Trystram, G. (2006a). Influence of egg type, pressure and mode of incorporation on density and bubble distribution of a lady finger batter. *Journal of Food Engineering*, *74*(2), 198-210.

Anderson, D. M. W., & Andon, S. A. (1988). Water-soluble food gums and their role in product development. *Cereal foods world (USA)*.

Apling, E. C., Khan, P., & Ellis, P. R. (1978). Guar/wheat bread for therapeutic use. *Cereal Foods World (USA)*.

Armero, E., & Collar, C. (1996). Antistaling additives, flour type and sourdough process effects on functionality of wheat doughs. *Journal of food science*, *61*(2), 299-303.

Ayoubi, A., HABIBI, N. M., & KARIMI, M. (2009). Effect of whey protein concentrate, guar and xanthan gums on the quality and physicochemical properties of muffin cake. *Iranian Food Science and Technology Research Journal, 4(2),*32-46.

Beikzadeh, S., Homayouni-Rad, A., Beikzadeh, M., & Peighambardoust, S. H. (2017). Effects of Psyllium and Marve Seed Mucilages on Physical, Sensory and Staling Properties of Sponge Cake. *Journal of Agricultural Science and Technology*, 19, 1079-1089

Beikzadeh, S., Peighambardoust, S. H., Beikzadeh, M., & Asghari Javar-abadi, M. (2018). Effect of psyllium seed and xanthan gums on physical, sensory and staling properties of sponge cake. *Food Science and Technology*, *15*(76), 152-141.

Bench, A. (2007). Water Binders for Better Body: Improving Texture and Stability with Natural Hydrocolloids. *Food and Beverage Asia*, 32-3.

Biliaderis, C. G., Arvanitoyannis, I., Izydorczyk, M. S., & Prokopowich, D. J. (1997). Effect of hydrocolloids on gelatinization and structure formation in concentrated waxy maize and wheat starch gels. *Starch‐Stärke*, *49*(7‐8), 278-283.

Chaplin, M. F. (2003). Fibre and water binding. *Proceedings of the Nutrition Society*, *62*(1), 223-227.

Collar, C., Martinez, J. C., & Rosell, C. M. (2001). Lipid binding of fresh and stored formulated wheat breads. Relationships with dough and bread technological performance. *Food Science and Technology International*, *7*(6), 501-510.

Dadkhah, A., Hashemiravan, M., & Seyedain-Ardebili, M. (2012). Effect of shortening replacement with nutrim oat bran on chemical and physical properties of shortened cakes. *Annals of Biological Research*, *3*(6), 2682-2687.

Davidou, S., Le Meste, M., Debever, E., & Bekaert, D. J. F. H. (1996). A contribution to the study of staling of white bread: effect of water and hydrocolloid. *Food hydrocolloids*, *10*(4), 375-383.

Deters, A., Zippel, J., Hellenbrand, N., Pappai, D., Possemeyer, C., & Hensel, A. (2010). Aqueous extracts and polysaccharides from Marshmallow roots (Althea officinalis L.): Cellular internalisation and stimulation of cell physiology of human epithelial cells in vitro. *Journal of ethnopharmacology*, *127*(1), 62-69.

Dikeman, C. L., & Fahey Jr, G. C. (2006). Viscosity as related to dietary fiber: a review. *Critical reviews in food science and nutrition*, *46*(8), 649-663.

Fernandez, L., Castillero, C., & Aguilera, J. M. (2005). An application of image analysis to dehydration of apple discs. *Journal of Food Engineering*, *67*(1-2), 185-193.

Friend, C. P., Waniska, R. D., & Rooney, L. W. (1993). Effects of hydrocolloids on processing and qualities of wheat tortillas. *Cereal Chemistry*, *70*, 252-252.

Gelinas, P., Roy, G., & Guillet, M. (1999). Relative effects of ingredients on cake staling based on an accelerated shelf-life test. *Journal of Food Science*, *64*(5), 937-940.

Gomez, M., Moraleja, A., Oliete, B., Ruiz, E., & Caballero, P. A. (2010). Effect of fibre size on the quality of fibre-enriched layer cakes. *LWT-Food Science and Technology*, *43*(1), 33-38.

Gomez, M., Oliete, B., Rosell, C. M., Pando, V., & Fernández, E. (2008). Studies on cake quality made of wheat–chickpea flour blends. *LWT-Food Science and Technology*, *41*(9), 1701-1709.

Gomez, M., Ronda, F., Caballero, P. A., Blanco, C. A., & Rosell, C. M. (2007). Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food hydrocolloids*, *21*(2), 167-173.

Hage-Sleiman, R., Mroueh, M., & Daher, C. F. (2011). Pharmacological evaluation of aqueous extract of Althaea officinalis flower grown in Lebanon. *Pharmaceutical biology*, *49*(3), 327-333.

Hajmohammadi, A., Keramat, J., Hojjatoleslami, M., & Molavi, H. (2014). Evaluation effect of tragacanth gum on quality properties of sponge cake. *Iranian Journal of Food Science Technology*, *42*(11), 1-8.

Hesarinejad, M. A., Siyar, Z. and Rezaiyan Attar, F. (2019) 'Investigating the effect of wheat flour enrichment with Phaseolus vulgaris flour on the physical, sensory and shelf-life characteristics of sponge cake', Food Science and Technology. *Food Science and Technology*, 16(86), pp. 213–222.

Hesarinejad, M.A., Rezaiyan, A. F., Mosaffa, O., & Shokrolahi, Y. B. (2017). The effect of incorporation of chlorella vulgaris into cake as an egg white substitute on physical and sensory properties. *Iranian journal of food science and technology*, 14(68), 61-72.

Hosseini Ghaboos, S. H., Seyedain Ardabili, S. M., & Kashaninejad, M. (2018). Physico-chemical, textural and sensory evaluation of sponge cake supplemented with pumpkin flour. *International Food Research Journal*, *25*(2).

Hug-Iten, S., Escher, F., & Conde-Petit, B. (2003). Staling of bread: Role of amylose and amylopectin and influence of starch-degrading enzymes. *Cereal Chemistry*, *80*(6), 654-661.

Kalinga, D., & Mishra, V. K. (2009). Rheological and physical properties of low fat cakes produced by addition of cereal β-glucan concentrates. *Journal of Food Processing and Preservation*, *33*(3), 384-400.

Kim, J. C., & De Ruiter, D. (1968). Bread from non-wheat flours. *Food Technology*, *22*(7), 867-878.

Koocheki, A., & Hesarinejad, M. A. (2016). Effect of freezing, pasteurization and sterilization on physical properties of oil-in-water stabilized with Lepidium perfoliatum seed gum and whey protein concentrate. *Food Science and Technology*, *14*(64), 31-21.

Koocheki, A., & Hesarinejad, M. A. (2019a). Qodume Shahri (Lepidium perfoliatum) Seed Gum. *Emerging Natural Hydrocolloids: Rheology and Functions*, 251-272.

Koocheki, A., & Hesarinejad, M. A. (2019b). Qodume Shirazi (Alyssum homolocarpum) Seed Gum. *Emerging Natural Hydrocolloids: Rheology and Functions*, 205-223.

Lazaridou, A., Duta, D., Papageorgiou, M., Belc, N., & Biliaderis, C. G. (2007). Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. *Journal of food engineering*, *79*(3), 1033-1047.

Lebesi, D. M., & Tzia, C. (2011). Effect of the addition of different dietary fiber and edible cereal bran sources on the baking and sensory characteristics of cupcakes. *Food and bioprocess technology*, *4*(5), 710-722.

Lee, C.C., Wang H. F. and Lin S. D. 2008. Effect of Isomaltooligosaccharide Syrup on Quality Characteristics of Sponge Cake. *Cereal Chemistry, 85:* 515-521

McCarthy, D. F., Gallagher, E., Gormley, T. R., Schober, T. J., & Arendt, E. K. (2005). Application of response surface methodology in the development of gluten-free bread. *Cereal chemistry*, *82*(5), 609-615.

Miller, R. A., & Hoseney, R. C. (1993). The role of xanthan gum in white layer cakes. *Cereal chemistry (USA)*.

Mousavi, S. F., Razavi, S. M., & Koocheki, A. (2019). Marshmallow (Althaea officinalis) Flower Gum. *Emerging Natural Hydrocolloids: Rheology and Functions*, 397-423.

Naqvi, S. A., Khan, M. M., Shahid, M., Jaskani, M. J., Khan, I. A., Zuber, M., & Zia, K. M. (2011). Biochemical profiling of mucilage extracted from seeds of different citrus rootstocks. *Carbohydrate polymers*, *83*(2), 623-628.

Oakenfull, D., Miyoshi, E., Nishinari, K., & Scott, A. (1999). Rheological and thermal properties of milk gels formed with κ-carrageenan. I. Sodium caseinate. *Food Hydrocolloids*, *13*(6), 525-533.

Pedreschi, F., Leon, J., Mery, D., Moyano, P., Pedreschi, R., Kaack, K., & Granby, K. (2007). Color development and acrylamide content of pre-dried potato chips. *Journal of food Engineering*, *79*(3), 786-793.

Peighambardoust, S.H., Homayouni Rad, A., Beikzadeh, S., Asghari Jafar Aabadi M., Beikzadeh M. (2016). Effect of basil seed mucilage on physical, sensory and staling properties of sponge cake. *Iranian Journal of Biosystems Engineering (Iranian Journal of Agricultural Sciences), 47(1),* 1-9.

Pierce, M. M., & Walker, C. E. (1987). Addition of sucrose fatty acid ester emulsifiers to sponge cakes. *Cereal Chem*, *64*(4), 222-225.

Rosell, C. M., Rojas, J. A., & De Barber, C. B. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food hydrocolloids*, *15*(1), 75-81.

Sadeghnia, N., Azizi, M. H., & Seyedin, M. (2011). Formulation and production gluten free flat bread by xanthan and CMC. *Master's thesis, Islamic Azad University [in Persian]*.

Sahraiyan, B., Karimi, M., Habibi Najafi, M. B., Hadad Khodaparast, M. H., Ghiafeh Davoodi, M., Sheikholeslami, Z., & Naghipour, F. (2014). The effect of Balangu Shirazi (Lallemantiaroyleana) gum on quantitative and qualitative of surghum gluten free bread. *Iranian Journal of Food Sciience and Technology*, *42*(11), 129-139.

Schiraldi, A., Piazza, L., Brenna, O., & Vittadini, E. (1996). Structure and properties of bread dough and crumb. *Journal of thermal analysis*, *47*(5), 1339-1360.

Shakouie, B. E., Peighambardoust, S. H., azadmard, D. S., Hesari, J., & Rafat, S. A. (2013). Effects of different levels of xylitol on physical and sensory characteristics of sugar-free cake. *Journal of Food Research (University of Tabriz), 23(3),* 435-444.

Shalini, K. G., & Laxmi, A. (2007). Influence of additives on rheological characteristics of whole-wheat dough and quality of Chapatti (Indian unleavened Flat bread) Part I—hydrocolloids. *Food hydrocolloids*, *21*(1), 110-117.

Sheikholeslami, Z., Karimi, M., GHAFEH, D. M., Sahraiyan, B., Naghipour, F., & Madani, S. (2017). Evaluation of qualitative, visual and sensory properties of cake containing native gum and natural emulsifier. Iranian Journal of Food Science and Technology, 14(68), 237-249.

Shokri Busjin, Z. (2004). *Evaluation of relationship between structure, operational and rheological properties of tragacanth gum and comparison with Arabic gum and it's utilization in a cake* (Doctoral dissertation, MSc Thesis. Isfahan: University of Technology,[in Persian]).

Sidhu, J. P. S., & Bawa, A. S. (2002). Dough characteristics and baking studies of wheat flour fortified with xanthan gum. *International Journal of Food Properties*, *5*(1), 1-11.

Song, K. Y., Joung, K. Y., Shin, S. Y., & Kim, Y. S. (2017). Effects of Basil (Ocimum basilicum L.) Seed mucilage substituted for fat source in sponge cake: physicochemical, structural, and retrogradation properties. *Italian Journal of Food Science*, *29*(4).

Sowmya, M., Jeyarani, T., Jyotsna, R., & Indrani, D. (2009). Effect of replacement of fat with sesame oil and additives on rheological, microstructural, quality characteristics and fatty acid profile of cakes. *Food Hydrocolloids*, *23*(7), 1827-1836.

Swami, S. B., Das, S. K., & Maiti, B. (2004). Effect of water and air content on the rheological properties of black gram batter. *Journal of food engineering*, *65*(2), 189-196.

Tavakolipour, H., & KALBASI-ASHTARI, A. H. M. A. D. (2007). Influence of gums on dough properties and flat bread quality of two persian wheat varieties. *Journal of food process engineering*, *30*(1), 74-87.

Toufeili, I. M. A. D., Dagher, S. H. A. W. K. Y., Shadarevian, S. O. S. S. Y., Noureddine, A. B. I. R., Sarakbi, M., & Farran, M. T. (1994). Formulation of gluten-free pocket-type flat breads: Optimization of methylcellulose, gum arabic, and egg albumen levels by response surface methodology. *Cereal Chemistry*, *71*(6), 594-600.

Young, W. E., & Bayfield, E. G. (1963). Hydrophilic colloids as additives in white layer cakes. *Cereal Chemistry*, *40*, 195-207.

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بررسی تأثیر افزودن موسیلاژ ختمی بر ویژگی‌های کیفی، فیزیکی و حسی کیک فنجانی

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چکیده

در این پژوهش عملکرد موسیلاژ ختمی (*Althaea officinalis* mucilage) بر ویژگی‌های کیفی کیک فنجانی و پتانسیل استفاده از آن در کنترل بیاتی مورد بررسی قرار گرفته است. برای این منظور، اثر غلظت‌های مختلف موسیلاژ ختمی (صفر، 0/25، 0/5 و 1 درصد) بر ویژگی‌های فیزیکی، سختی، رنگ و ویژگی‌های حسی کیک فنجانی و خمیر آن تعیین شد. به‌طور کلی، ویژگی‌های کیک با افزودن موسیلاژ تحت تأثیر قرار گرفت. نتایج نشان داد که افزودن موسیلاژ به‌طور معنی‌داری ($p<0/05$) باعث بهبود خصوصیات فیزیکی کیک و خمیر شامل رطوبت، حجم مخصوص، دانسیته و ویسکوزیته در مقایسه با نمونه شاهد شد. با افزودن موسیلاژ به کیک، سختی بافت در طول ذخیره‌سازی به‌طور قابل توجهی کاهش یافته است. نتایج حاصل از مقایسه میانگین پارامترهای رنگی نشان داد که کمترین مقدار روشنایی پوسته کیک (L^*) متعلق به نمونه شاهد و بیشترین مقدار آن مربوط به نمونه‌های حاوی 0/25 و 1 درصد موسیلاژ بودند. کیک‌های با 0/75 و 1 درصد موسیلاژ بالاترین امتیاز ارزیابی حسی را کسب کردند.

واژه‌های کلیدی: موسیلاژ ختمی، ویژگی‌های حسی، کیفیت، کیک فنجانی.

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Research Full Papers

Vitamin protection by Alginate-Whey Protein Micro Gel (AL-WPC MG) as a novel microcapsule against gastrointestinal condition; case study: B-complex vitamins.

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Abstract

The aim of the current research was to identify and develop an ideal delivery system in order to protect the vitamin from gastrointestinal conditions. For this purpose, vitamin loaded Alginate-Whey protein micro gels (AL-WPC MGs) developed as a biopolymer carrier. This microcapsule was examined in terms of morphology, ζ-potential particle size and distribution, encapsulation and delivery efficiency, and in vitro gastric and intestinal digestions. Absorbance method was used to monitor B-complex vitamins release over time at the simulated gastrointestinal conditions. Release experiments illustrated beneficial attributes for these microspheres. Release mechanism was predicted by using various kinetic equations. Results indicated that the most of the fabricated spherical shaped AL-WPC MGs was under 100 µm in size, and these microcapsules had an excellent and moderate stability in gastric and intestinal conditions, respectively. It was found that the highest vitamin release rate occurs in the simulated gastric-intestinal situation, and type of the vitamin had a slight effect on the release rate and release profile. Kinetic models suggested that release from group B vitamins mainly was controlled by Fickian diffusion mechanism. In general, this research showed that the AL-WPC MGs protect the vitamin from gastric digestion and could be used as a delivery system.

In previous works, a novel AL-WP MGs and use for different active agent encapsulation was developed, while the final purpose of this work was to study the vitamin release mechanism from AL-WPC MGs at the gastro–intestinal situation. Accordingly, this microcapsule showed the highest vitamin release rate at the simulated intestinal situation. This high release could be due to instability of alginate in neutral pH, and also enzymatic digestion of whey protein. The better release of vitamin at intestinal condition is desirable to achieve the nutrient effect during food consumption. This micro gel therefore appears to be potentially beneficial as digestion delivery vehicles for bioactive compounds in the food and nutraceuticals industry as well as non-food industry.

Keywords: B-complex vitamin, control release, micro gel, whey protein, alginate

Introduction

Vitamins as a micronutrient are a group of organic compounds that are needed in small quantities for the body metabolism to work properly and stay healthy. Vitamins are classified into two categories including fat soluble (vitamins A, D, E, and K) and water soluble (vitamins C and the B-complex vitamins). Water-soluble vitamins are a sensitive and cannot stay in body. One of the water-soluble vitamins are the group B (or B complex) vitamins, which has vital roles in metabolic processes such as a red blood cell formation and energy production. B-complex vitamins classified into 8 categories including B_1 (thiamine), B_2 (riboflavin), B_3 (niacin), B_5 (pantothenic acid), B_6 (pyridoxine), B_7 or H (biotin), B_9 or B_{11} of M (folate), B_{12} (cobalamin) (LeBlanc et al., 2011; Beck, 2001; Molina et al., 2009). Many cereals are one of the richest sources of B complex vitamins; however fish, poultry, meat, eggs, dairy products, Leafy green vegetables, beans, peas also has a good level of group B vitamins (Moll and Davis, 2017; Beck, 2001).

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Many of these nutrients are essential to regulate vital biochemical reactions in the cell and cannot synthesize in the living organisms or synthesize in insufficient level; therefore, most of them should be provided by diet. In the recent decade, vitamin deficiencies occur in many societies because of malnutrition or unbalanced diets; thus, fortification of food with vitamins is necessity. Although most of the natural food substance (unprocessed food) has enough vitamin level; but usually food processing and storage cause the greatest vitamin loss. When, food passing from gastrointestinal system, nutrient exposed to the hard condition such as an acidic pH and easily destroyed. Due to the decreasing of vitamin loss, there is a need for encapsulation of these micronutrients to protect them from processing, storage and gastrointestinal conditions and also any undesirable interaction or reaction with the environment. This capsule must intelligently act to achieve a lower gastric release but a faster intestinal release (LeBlanc *et al*., 2011; Beck, 2001; Moschona and Liakopoulou-Kyriakides, 2018; Abbasi *et al.*, 2018).

Encapsulation is the best delivery vehicle that enables enhanced the stability and bioavailability of an active agent against the gastrointestinal conditions. Such entrapping vesicular system could release their core material from semi porous shell under the specific situation (namely controlled release). Various shell materials and different methods are being used by researchers for fabrication of special delivery systems that typically have to be particularly designed for each application; however, some of them are effective, safe, cheap, and applicable (Cheong *et al.*, 2016; Fani *et al.*, 2017; Jafari, 2017; Zandi *et al*., 2014; Zandi and Mohebbei, 2014; Zandi *et al.*, 2017; McClements, 2015; Oehlke *et al.*, 2014; Zhang *et al.* 2016). Recently, food grade protein- polysaccharide interaction as a promising delivery vehicle has been considerable interest. Lately, Alginate-Whey protein micro gels (AL-WP MGs) used as biopolymer carriers and candidate for targeted release system. AL-WP MGs are soft and small particle that usually less than 100 μm in size (Lamas *et al*., 2001).

AL-WP MGs were made via whey protein isolated (or whey protein concentration) and sodium alginate using emulsification/ internal gelatin method. Whey protein is extensively used as food ingredients because they have unique properties include high nutritional values, water-binding, foaming stabilizing, emulsion stabilizing, good gel producing, and thickening properties. Whey protein may be used as carriers for hydrophobic substances in food products and pharmaceutical (Leon *et al*., 2018) (Abbasi *et al.*, 2018). The alginate polymer consists of linear copolymers of β-(1-4) linked D-mannuronic acid and α-(1-4)-linked L-guluronic acid (G) residues which is able to form pH-sensitive and temperature-independent hydrogels. This attractive polymer could be used as a component of a delivery matrix for lipophilic active and bio-active agents (Ni *et al*., 2015). Ionic crosslinking with cations (ionic gels) or acid precipitation (acidic gels) are used as two methods for alginate gel formation (Ching *et al.*, 2017; Koutina *et al.*, 2018; Bouyer *et al.*, 2012). For active agent encapsulation, sodium alginate solution containing the bioactive is injected into whey protein solution that results in the formation of soft and moist cold AL-WP MGs (Zhang *et al.*, 2016). Due to AL-WP MGs mechanical and viscoelastic properties; these types of microcapsules could use for the nutrient (Zandi, 2017; Zandi *et al.*, 2017) flavors (Zandi *et al.*, 2014), Drug and other active and bioactive agents (Zandi *et al.*, 2017; Abbasi *et al.*, 2018; Chen and Subirade, 2006) encapsulation in a wide range of research and industry applications (Zhang *et al.*, 2015; Zhang *et al.*, 2016). AL-WP MGs can protect the vitamin from the acidic situation in the stomach and make them available in the intestines for increased bioavailability (Wichchukit *et al.*, 2013).

In prior works (Zandi, 2017; Zandi *et al.*, 2014; Zandi *et al.*, 2017; Zandi and Mohebbei, 2015) we developed novel AL-WP MGs and use for different active agent encapsulation. Such microspheres should be degraded by intestines condition, allowing vitamin release. The model vitamin were group B vitamin. For this purpose, release mechanism, kinetic and profile of an encapsulated any vitamins through the AL-WP MGs shell at the gastrointestinal situation was investigated by spectrophotometry technique; then kinetic models were fitted to the experimental release data for release kinetic prediction. Finally, the influence of consumption condition on the encapsulation, retention and release of the vitamins were then measured.

Method and material

Whey protein concentrate with 80% protein and 4% moisture content was purchased from Davisco Foods International Inc. (USA). Sodium alginate (sodium salt, 99.5%), sodium hydroxide, potassium dihydrogen phosphate, hydrochloric acid, sodium bicarbonate, analytical grade pepsin and pancreatic enzymes, calcium chloride (Sigma Aldrich, St. Louis, MO; > 93%) and deionized water of resistivity 18.2 MΩ·cm were purchased from the Sigma Chemical Company (St. Louis, MO, USA). Tween 80 (Fluka, Switzerland), sunflower oil (from the supermarket), sodium chloride (Fluka) were used without further purification. Thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, folate, biotin and cobalamin were supplied by Sigma Chemical Co., (St. Louis, MO, USA). Double distilled water was used to make all solutions. All other reagents were of analytical grade and acquired from Merck co (Germany).

AL-WP MGs fabrication via Ultrasonication

AL-WP MGs loaded with group B vitamin was prepared based on Zandi et al. (2014, 2017) technique with slighted modification. 2% (w/v) Alginate (AL) solution and 8% (w/v) Whey Protein concentrate (WP) was prepared by dissolving both ingredients separately in deionized water at room temperature under mild agitation for 1 h using a magnetic stirrer (IKAWerke GmbH&Co. KG, model RH basis). The resulting solution was held overnight at 4℃ to ensure complete and proper hydration of the components. WP solution adjusted to pH= 8 and was left at room temperature for 2 h, then it was heated at a temperature controlled water bath at 80°C for 30 min to denature and aggregate the WP. Heating stage facilitates the formation of stable WP emulsion structures. WP solution was cooled and kept at room temperature for 2 h. then WP (80% wt) and AL (20% wt) were mixed and stirred for 30h at room temperature. The obtained formulation was allowed to stand overnight at 4℃ . To prepare VitB- AL–WP emulsion, AL–WP solution (20% v/v), Tween 80 (0.05% v/v)), group B vitamin (0.05% v/v) and sunflower oil (20% v/v) were blended and stirred with a high-speed blender (Ultra Turrax digital T25, IKA-Werke, Germany) for 5 min at 8,000 rpm. For sustained release experiments, B complex vitamins prepared under minimum light exposure to prevent vitamin degradation.

To prepare emulsion containing Ca, sunflower oil (60% v/v), tween 80 (0.05% v/v) and calcium chloride solution 0.1 M (0.05% v/v) were subjected to ultra-sonication at a 24 kHz frequency with 50% of amplitude for 5 min (Hielscher UP400S, Germany). To form a micro gel, 32 ml of emulsion containing Ca was gently added to the 120 ml of VitB- AL–WP emulsion and blended for 20 min at 100 rpm; then 50 ml of calcium chloride solution 0.05 M was added to resulted emulsion. After complete partitioning of droplets to the aqueous phase (about 40 min), white sediment was separated from the creamed oil and they were washed with the solution of calcium chloride 0.05 M and tween 1%. Finally, fabricated AL-WP MGs were filtered using a Millipore glass vacuum filtration system with 0.65 μm cellulose nitrate membranes filter (ALBET). The obtained AL-WP MGs containing vitamin were used immediately to minimize loss of active agent.

AL-WP MGs Characterization

Particle size measurements

The average hydrodynamic diameter and particle size distribution of the AL-WP MGs were determined on fresh diluted samples using dynamic light scattering (Zetasizer Nano ZS, Malvern Instruments, Worcestershire, UK). Also, sizes were measured via an optical microscope equipped with a digital camera; AL-WP MGs diameters estimated were by image J software (version 1.46r).

AL-WP MGs morphology

The microstructure of the dried AL-WP MGs coated using platinum was examined using Leo 1450VP SEM microscope at 5.0 kV. Shape and structure of AL-WP MGs were acquired with Olympus BX41 transmitted light microscope equipped with a Nikon digital camera (Nikon Corp., Tokyo Japan).

ζ-potential measurements

ζ-potential of AL-WP MGs were examined via Malvern Instruments Zetasizer Nano ZS device (Malvern Ltd., UK) using the clear solution of microsphere. All experiment were conducted in three separated injections.

Encapsulation and delivery efficiency

The encapsulation efficiency (EE, %) was determined by dividing the amount of vitamin encapsulated (VE) to the total amount of vitamin (TV) (Zandi, 2017):

$$EE(\%) = \frac{VE}{TV} \times 100 \quad (1)$$

The delivery efficiency (DE) is a capability of the microcapsule to delivery active agent at special condition; this parameter was calculated from the initial (VI) and final (VF) masses of encapsulated vitamin (Zandi, 2017):

$$\mathrm{DE}(\%) = \frac{\mathrm{VI}-\mathrm{VF}}{\mathrm{VI}} \times 100 \quad (2)$$

Simulation of gastrointestinal condition

The artificial gastric and intestinal fluids were prepared using Zhang et al. (1981) instruction. The produced simulated intestinal fluid consisted of 10 g of pancreatin and 0.05 mol of potassium dihydrogen phosphate at pH=7. Simulated gastric fluid was prepared by dissolving 2 g of sodium chloride and 3.2 g of pepsin in deionized water at pH=3.

In vitro AL-WP MGs release studies

Release study through the AL-WP MGs shell was investigated at the three different media, including (Zandi, 2017):

Simulated gastric condition

Incubation of 1 g of the wet capsule with 9 ml of the simulated gastric fluid at the 37°C (pH=3) for 150 min with shaking (500 rpm).

Simulated intestinal condition

Incubation of 1 g of the wet capsule with 9 ml of the simulated intestinal fluid at the 37°C (pH=7) for 210 min with shaking (500 rpm).

Simulated gastric-intestinal condition

first, incubation of 1 g of the wet capsule with 9 ml of the simulated gastric fluid at the 37°C (pH=3) for 150 min with shaking (500 rpm), and then added 10 ml of the simulated intestinal fluid to the mixture and incubation the 37°C (pH=7) for 210 min with shaking (500 rpm).

The concentration of the Group B vitamins in the surrounding aqueous phase was measured at various time intervals (30 min) by spectrophotometry method via WPA Lightwave s2000 UV-visible spectro-photometer, (Centerville, VA, U.S.) equipped with a silica cuvette. Sample was filtered through 0.22-lm Biofil syringe filter. Absorbance of final sample at 246 (Ghasemi and Abbasi, 2005), 445 (Chen and Subirade, 2006), 464 (Nwanisobi and Ukoha, 2016), 288 (Khateeb, *et al.*, 2015), 292 (Ghasemi and Abbasi, 2005), 285 (Ghasemi and Abbasi, 2005), 348 (Walash *et al.*, 2008) and 317 (Bruno, 1981) nm were obtained for Thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, folate, biotin and cobalamin, respectively. Standard solution of vitamin and deionized water were used as a calibration sample and zero reference respectively. The AL-WP MGs studies were was repeated three times to verify reproducibility.

AL-WP MGs release Kinetics

In the present research, AL-WP MGs release profile was interpreted with various mathematical models (Dash *et al.*, 2010; Zandi *et al.*, 2014)

Zero order model: $C_t = C_0 + K_0 t$ (3)

C_t is the amount of vitamin released at time t, C_0 is the initial concentration of d vitamin rug at time $t = 0$, and K_0 is the zero-order rate constant.

First order model: $\log C_t = \log C_0 - \frac{K_1 t}{2.303}$ (4)

K_1 is the first order rate constant ($time^{-1}$ or per hour).

Korsmeyer -Peppas model:

$\log(\frac{C_t}{C_\infty}) = \log K_{Kp} + n \log t$ (5)

C_∞ is the amount of vitamin released after time ∞, K_{Kp} is the Korsmeyer release rate constant, and n is the diffusional exponent or drug release exponent.

Kopcha model: $C_t = A \times t^{0.5} + B \times t$ (6)

A and B are the Kopcha constant, and t is the time.

Statistical analysis

Experiments were analyzed using a completely randomized design with repeated measures with the significance level set at $p \leq 0.05$. All statistical analyses and Duncan's post hoc test were carried out at least in triplicate using the SPSS 21.0 statistical software (IBM Corporation, New York City, New York, United States) and graphs' error bars were obtained. All data fittings were accomplished using Matlab software (R2007), and the best model was identified by measuring the correlation coefficient of determination (R^2).

Results and discussion

AL-WP MGs Characterization

Scanning Electron Microscopy (SEM) image obtained for the fabricated AL-WP MGs are depicted in Fig. 1.

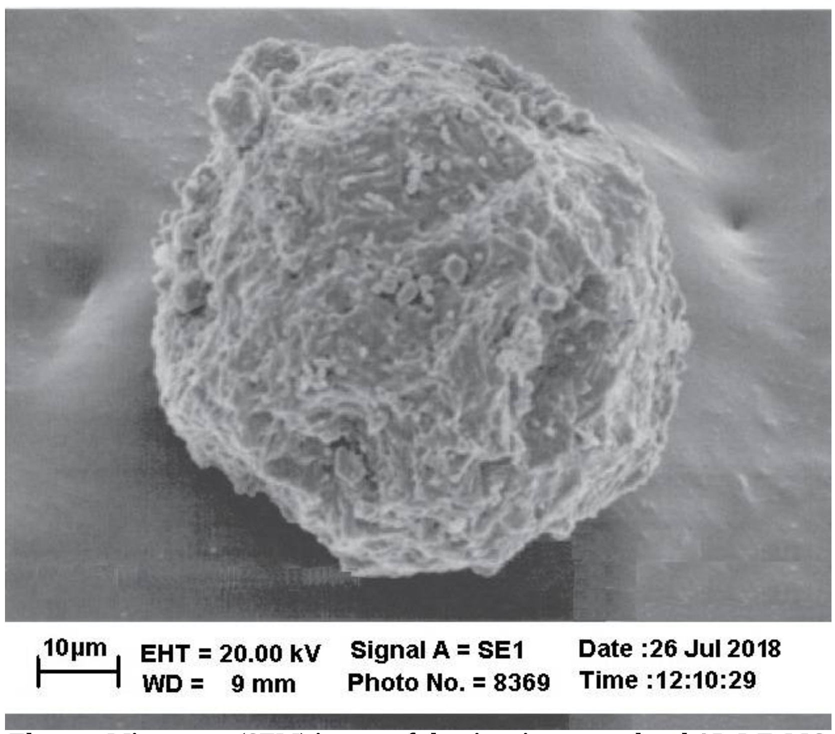

Fig. 1. Scanning Electron Microscope (SEM) images of the vitamin encapsulated AL-WP MGs.

Inspection of images shows that the shape of AL-WP MGs were found to have an almost spherical structure with smoothed and porous shell. This structure probably was developed by the cross-linking of whey protein and alginate by using carboxyl groups (Zandi *et al.*, 2014). Spherical shape was formed due to the exposing of the hydrophilic and hydrophobic the whey protein side chains, respectively, to the solution and core (Zandi, 2017). As shown in Fig. 2, optical micrograph of AL-WP MGs obtained from light microscopy images confirmed the SEM results. Moreover, it can be seen that most of the resulted AL-WP MGs are under 100 μm in size.

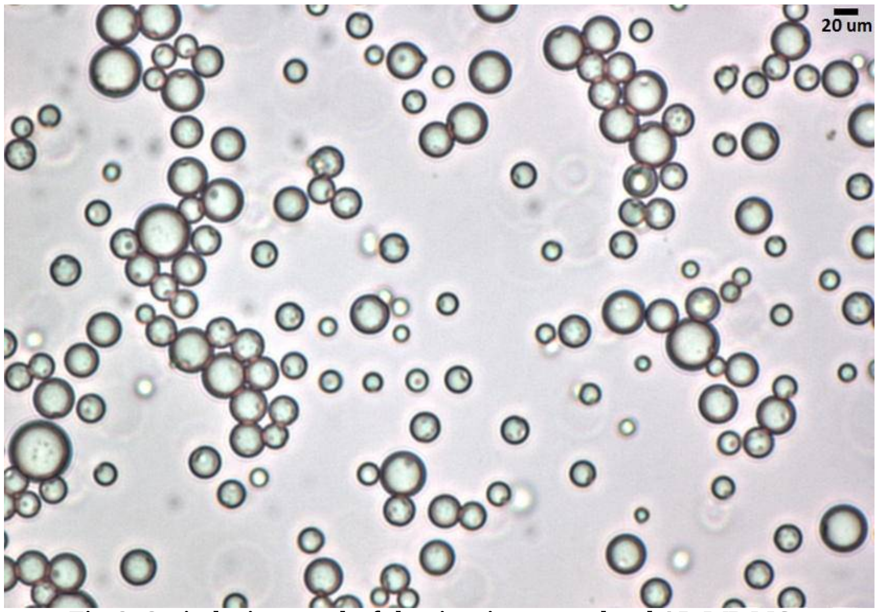

Fig. 2. Optical micrograph of the vitamin encapsulated AL-WP MGs.

The mean diameter of AL-WP MGs were obtained by two different methods. The mean diameter of microcapsule was calculated via image analyzing technique from optical images using ImageJ software (version 1.46r). In this software the equivalent size of AL-WP MGs as the diameter of a circle with equal area were estimated. Image processing results revealed that the diameter of AL-WP MGs range varying between 40–95 μm with an average diameter of 75± 1.3 μm (mean value± SD for n= 50). The size of AL-WP MGs was less than the size range reported by our previous research and other studies (Zandi and Mohebbei, 2015; Zandi, 2017; Zandi *et al*., 2017; Chen and Subirade, 2006). This decreased in the mean diameter might be related to the slight modification the AL-WP MGs fabrication technique and using sonication by ultrasound. This difference confirms that emulsification by ultrasound generally results in average diameters smaller than those obtained with mechanical agitation (Leon *et al*., 2016). By increasing the rate or/ and time of emulsification process, smaller micro gel size can be generated. Particle size distribution curve of AL-WP MGs obtained by dynamic light scattering (DLS) are depicted in Fig. 3. Ity can be seen that the fabricated AL-WP MGs ranging from 35 to 98 μm in size with the mean hydrodynamic diameter 75± 1.3μm. This result has a good correlation with the image processing finding.

The ζ-potential of AL-WP MGs as a function of pH (acidic [gastric] and neutral [intestinal] conditions) were measured.

ζ-potential typically ranges between -100 to +100 mV, and was used to assess the potential stability (Abbasi *et al.,* 2018). For small particles, a higher ζ-potential (negative or positive) will confer stability. So, particles with high ζ-potential are electrically stabilized while particles with low ζ-potential tend to coagulate or flocculate. The ζ-potential values of the AL-WP MGs were abound -68 mV at pH=3 (gastric condition) followed by -14 mV for pH =7 (intestinal situation). These measurements illustrated that the pH had a significant ($P<0.05$) effect on the AL-WP MGs’ stability, and these microcapsules had an excellent and moderate stability in gastric and intestinal condition, respectively. McClements mentioned that multilayered emulsion as a microcapsule have improved stability to environmental stresses than those stabilized by one-layered shell (McClements, 2004; Abbasi *et al.*, 2018).

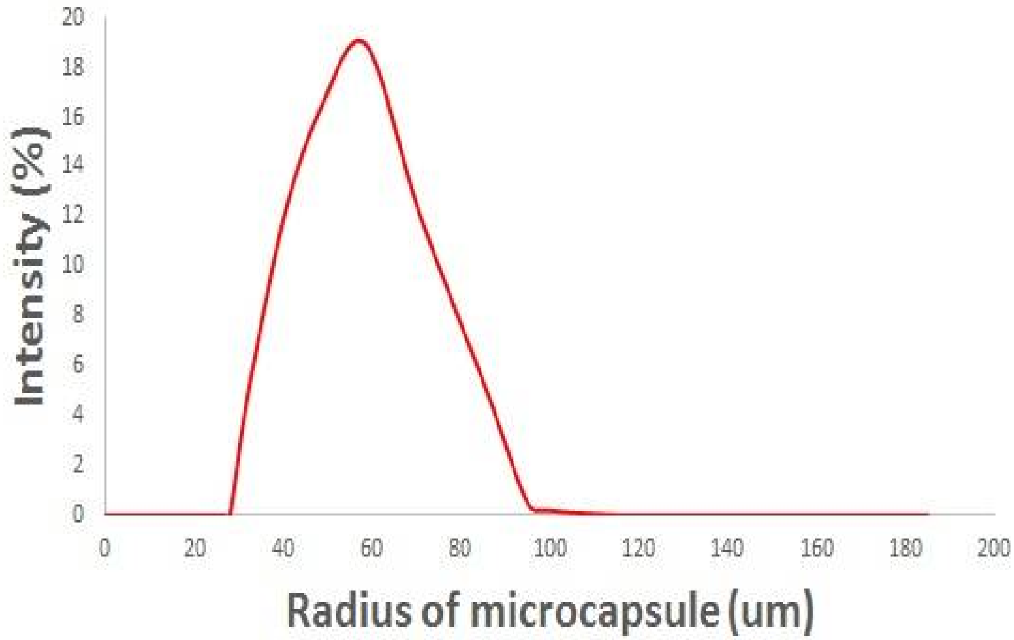

Fig 3. Particle size distribution curve of AL-WP MGs.

Encapsulation efficiency and delivery efficiency of AL-WP MGs

Encapsulation efficiency is often defined as the total amount of vitamin encapsulated in AL- WP MGs with respect to the total amount of the vitamin used. The encapsulation efficiency of AL- WP MGs loaded by thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folate, and cobalamin are shown in Table 1. As seen in Table 1, encapsulation efficiency ranged between 68.89 and 80.46%. Vitamin losses during encapsulation can be affected by the vitamin solubility, sonication time, active agent volatility, microcapsule's shell composite and porosity and emulsifier (Zandi, 2017; Abbasi *et al.*, 2018; Ghorbanzade et al., 2017). Since B complex vitamins are a low molecular weight water-soluble vitamins, its losses during the AL- WP MGs washing step is unavoidable. In current study, lower encapsulation efficiency was obtained for the thiamin encapsulated AL- WP MGs. About 30% of thiamin was lost because of the higher solubility compared to the other B complex vitamins. Results showed that AL-WP MGs contained cobalamin and riboflavin has a higher encapsulation efficiency. Generally it has been reported that the decreasing of solubility and sensitivity, results in better encapsulation efficiency and therefore a greater preservation of bioactive substances.

The Delivery Efficiency (DE) is a capability of the AL-WP MGs to deliver the vitamin at gastric, intestinal and gastric-intestinal conditions (Table 1). As seen in table 1, delivery efficiency ranged between 21.12 and 89.43% for various vitamins and different release situations. It was shown that the delivery efficiency of the AL-WP MGs was higher at simulated gastric-intestinal condition. The lower delivery efficiency reflected a greater resistance to vitamin release. The better delivery efficiency of the vitamin at gastric-intestinal condition is desirable to provide a better protection to the bioactive component in the stomach and a relatively fast release in the intestine.

Table 1. Encapsulation Efficiency (EE) and Delivery Efficiency (DE) of AL-WP MGs loaded by thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folate, and cobalamin.

AL-WP MGs loaded by vitamin	EE (%)	DE at gastric condition (%)	DE at intestinal condition (%)	DE at gastric-intestinal condition (%)
Thiamine	68.89±2.13	21.12±0.89	46.21±1.09	80.25±1.62
Riboflavin	80.46±1.47	26.31±1.12	48.16±1.35	87.74±1.59
Niacin	76.71±1.12	29.11±0.78	50.79±0.72	92.43±0.97
Pantothenic acid	71.64±1.87	23.75±1.24	47.84±1.59	84.74±0.86
Pyridoxine	70.28±1.65	27.98±1.31	48.21±1.42	89.69±1.10
Biotin	73.36±1.04	24.78±0.96	47.25±0.65	82.31±1.45
Folate	69.75±1.59	22.43±1.07	46.34±1.26	79.45±1.72
Cobalamin	77.13±1.56	28.68±0.93	49.57±1.12	88.18±1.32

In Vitro AL-WP MGs Release Studies

In this section, the effects of the release media on the released percentage from the AL-WP MGs was investigated. Vitamin release rate (%min) for various conditions are shown in table 2.

Table 2. Vitamin release rate (%/min) for various conditions

AL-WP MGs loaded by vitamin	release rate (%/min) at various conditions (% ± SD)		
	Gastric condition	**Intestinal condition**	**Gastric-intestinal condition**
Thiamine	0.1408±0.013	0.2200±0.012	0.2229±0.009
Riboflavin	0.1754±0.035	0.2290±0.009	0.2437±0.011
Niacin	0.1940±0.024	0.2389±0.010	0.2567±0.015
Pantothenic acid	0.1583±0.015	0.2275±0.008	0.2353±0.013
Pyridoxine	0.1865±0.023	0.2329±0.015	0.2491±0.018
Biotin	0.1652±0.018	0.2243±0.014	0.2286±0.017
Folate	0.1495±0.025	0.2231±0.021	0.2206±0.021
Cobalamin	0.1876±0.019	0.2340±0.013	0.2449±0.011

The in-vitro vitamin release experiments were accomplished in three different simulated conditions, including gastric, intestinal and gastric- intestinal. As expected, release media significantly ($P<0.05$) influenced the vitamin release rate and release profile from AL-WP MGs. This microcapsule showed the highest vitamin release rate at the simulated gastric-intestinal situation. This high release could be due to instability of alginate in neutral pH, and also enzymatic digestion of whey protein. Potent electrostatic interaction between whey protein and alginate in the microcapsule shell caused the stability of AL-WP MGs at the simulated gastric condition (pH=3) (6) (39). Zhang et al. (2016) reported that the protein-polysaccharide interaction depended on the molecular charge of protein and polysaccharide. Three main reasons could find for the WP MGs' stability at the stomach. First constancy of alginate in the acidic media, second, different electrical charge of the whey protein and alginate at acidic conditions and finally, protection effect of the alginate on the whey protein against the gastric enzymes (especially pepsin) via viscosity increasing (Zhang *et al*., 2016; Abbasi *et al*., 2018; Zandi, 2017; Zhang *et al*., 2016; Deat Lainea *et al.*, 2012). Whey protein and alginate strongly have tended to attract and repel each other at acidic and neutral pH, respectively. Therefore, AL-WP MGs at the neutral pH (i.e. intestinal condition) probably had an open structure with more and larger pores. This structure may be responsible for the faster release in the simulated intestinal condition (Zhang *et al.*, 2016). Our release results is in agreement with the pervious researches (Zandi, 2017) (Zhang, *et al*., 2015) (Chen and Subirade, 2006). It was found that type of the vitamin had a slighter effect on the release rate and release profile. The result indicated that vitamin release rate was increased with increases vitamin solubility.

Fig. 4 shows the typical profile of vitamin release from AL-WP MGs (for biotin). The release profiles were built by plotting the cumulative vitamin release percentile versus the release time. As clearly seen, the vitamin release profile has a two curve with the different slope. First, quick burst releases, and then a slow diffusion starts to release. Rapid release mainly occurs from holes and pores, and slow release corresponded to the diffusion mechanism through the AL-WP MGs' shell.

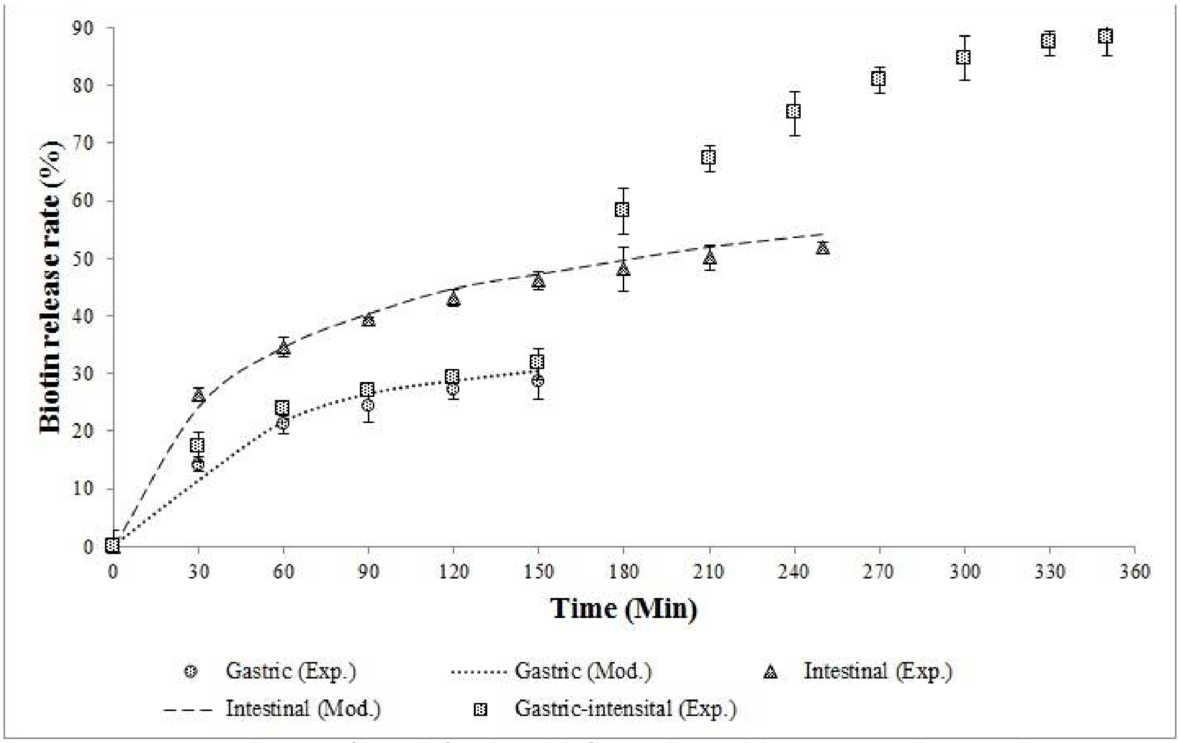

Fig. 4. Biotin release profile with fitted model (first-order model) at various release conditions.

Mathematical modeling for vitamin release kinetics

To investigate the vitamin release from AL-WP MGs at various situations, mathematical modeling was accomplished via various kinetic equations (including Zero Order model, First order model, Korsmeyer –Peppas model, and kopcha model) (Table 3, 4, 5). These kinetic equations were used to the vitamin release mechanism recognition, release rate prediction, and vitamin release physics understanding. For this purpose, experimental release data were fitted to the various kinetics models, and the best one was selected according to the regression coefficient evaluation. As seen, vitamin release profile was non-linear and doesn't follow zero-order model (R^2 between 21.43-36.72 in Table 3, 4, and 5).

The modeling results indicated that the first-order model could be the best describe for group B vitamins with R^2 between 97.43-99.15. However, the other mathematical model that best described vitamin releases from AL-WP MGs were Korsmeyer– Peppas model and kopcha model with R^2 values greater than 0.842. As observed in Table 4, the Korsmeyer–Peppas release exponent (n) ranged between 0.1014- 0.4313 which confirms that fickian diffusional release is the main mechanism. n is the diffusional exponent or drug release exponent. Hence, n value is used to characterize different release mechanisms; when the Korsmeyer– Peppas release exponent is less than 0.5, Fickian diffusion is the main mechanism for vitamin release. For more information about release mechanism, kopcha model was used. In this kinetic model, A and B are diffusional and erosional terms respectively. When A/B ratio is greater than 1, then fickian diffusional is the main mechanism of release. For this purepose must be A component far greater than B component. As seen in Table 4, the Korsmeyer– Peppas and Kopcha models suggested that release from group B vitamins mainly was controlled by Fickian diffusion mechanism.

Table 3. Results of model fitting of vitamin release from AL-WP MGs in simulated gastric condition

AL-WP MGs loaded by vitamin	Kinetic Models									
	Zero order		First order		Korsmeyer -Peppas			Kopcha		
	K_0	R^2	K_1	R^2	K_{Kp}	n	R^2	A	B	R^2
Thiamine	0.2312	25.36	0.0831	97.83	0.2653	0.1543	89.43	0.1998	-0.0231	95.93
Riboflavin	0.1321	27.85	0.1284	97.43	0.3214	0.2115	88.65	0.2111	-0.0344	97.15
Niacin	0.1432	21.43	0.1543	97.54	0.4321	0.2419	89.93	0.2243	-0.0451	96.49
Pantothenic acid	0.2127	29.43	0.1321	98.29	0.4215	0.1126	90.21	0.2831	-0.0387	98.54
Pyridoxine	0.2657	25.68	0.1654	99.08	0.3614	0.2078	89.67	0.2567	-0.0421	97.73
Biotin	0.2981	34.58	0.1023	98.43	0.3812	0.2012	91.12	0.2113	-0.0426	98.15
Folate	0.3021	36.71	0.0976	98.45	0.3314	0.2923	90.65	0.2017	-0.0349	96.31
Cobalamin	0.3012	35.98	0.1215	99.01	0.4341	0.2877	91.48	0.2165	-0.0409	98.11

Table 4. Results of model fitting of vitamin release from AL-WP MGs in simulated intestinal condition.

AL-WP MGs loaded by vitamin	Kinetic Models									
	Zero order		First order		Korsmeyer -Peppas			Kopcha		
	K_0	R^2	K_1	R^2	K_{Kp}	n	R^2	A	B	R^2
Thiamine	0.2921	28.45	0.1342	98.24	0.3654	0.2384	89.12	0.3123	-0.0317	97.47
Riboflavin	0.3021	29.41	0.1541	99.04	0.4532	0.3876	88.96	0.3651	-0.0288	98.30
Niacin	0.2121	32.31	0.1532	97.48	0.4431	0.2487	90.91	0.4567	-0.0412	98.57
Pantothenic acid	0.2541	35.45	0.1245	99.11	0.4832	0.3421	90.24	0.3217	-0.0406	97.26
Pyridoxine	0.2632	33.21	0.2341	98.67	0.4211	0.2987	90.65	0.4213	-0.0321	99.01
Biotin	0.2147	34.47	0.2126	97.19	0.3641	0.3218	89.36	0.2987	-0.0504	98.91
Folate	0.3076	29.93	0.2376	99.10	0.3523	0.3991	88.67	0.2876	-0.0419	98.40
Cobalamin	0.2431	28.54	0.2020	98.95	0.3971	0.3772	91.24	0.4965	-0.0287	98.75

Table 5. Results of model fitting of vitamin release from AL-WP MGs in simulated gastric-intestinal condition

AL-WP MGs loaded by vitamin	Kinetic Models									
	Zero order		First order		Korsmeyer -Peppas			Kopcha		
	K_0	R^2	K_1	R^2	K_{Kp}	n	R^2	A	B	R^2
Thiamine	0.2312	28.45	0.2851	98.76	0.4123	0.3217	89.67	0.4832	-0.0501	95.90
Riboflavin	0.2465	39.31	0.4321	99.15	0.4982	0.4313	90.54	0.4751	-0.0365	98.74
Niacin	0.4031	30.12	0.1243	98.45	0.5321	0.4215	90.36	0.4231	-0.0287	97.96
Pantothenic acid	0.3126	28.98	0.2356	99.01	0.5412	0.3254	91.11	0.4034	-0.0391	98.52
Pyridoxine	0.3216	34.23	0.2945	97.68	0.4321	0.3765	92.35	0.3657	-0.0402	98.01
Biotin	0.3021	35.59	0.2542	98.24	0.3987	0.3821	91.70	0.3987	-0.0294	97.45
Folate	0.2187	31.23	0.2098	98.99	0.4534	0.3954	92.16	0.3765	-0.0367	98.17
Cobalamin	0.3476	32.91	0.4231	98.43	0.4673	0.4212	90.07	0.4112	-0.0299	98.50

Conclusion

The focus of this work was to produce water-in-oil emulsion stabilized by whey protein and alginate to protect vitamin. Investigation of SEM image indicated that the shape of fabricated AL-WP MGs were found to have an almost spherical structure with an average diameter of 75± 1.3μm. The ζ-potential measurements illustrated that the pH had a significant (P<0.05) effect on the AL-WP MGs' stability. Accordingly, this microcapsule showed the highest vitamin release rate at the simulated gastric-intestinal situation. This high release could be due to instability of alginate in neutral pH, and also enzymatic digestion of whey protein. The results indicated that fickian diffusional release is the main mechanism for group B vitamins from AL-WP MGs. These micro gel therefore appears to be potentially beneficial as digestion delivery vehicles for bioactive compounds in the food and nutraceuticals industry as well as non-food industry.

Declaration of interest

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Reference

Abbasi, F, F Samadi, S M Jafari, S Ramezanpour, and M S Shargh. 2018. "Ultrasound-assisted preparation of flaxseed oil nanoemulsions coated with alginate-whey protein for targeted delivery of omega-3 fatty acids into the lower sections of gastrointestinal tract to enrich broiler meat." *Ultrasonics Sonochemistry.*

Beck, W S. 2001. *In Handbook of Vitamins, 3rd edn ed*. Edited by R Rucker, J Sutie, D B McCormick and L J Machlin. New York: Marcell Dekker.

Bouyer, E, G Mekhloufi, V Rosilio, J L Grossiord, and F Agnely. 2012. "Proteins, polysaccharides, and their complexes used as stabilizers for emulsions: Alternatives to synthetic surfactants in the pharmaceutical field?" *International Journal of Pharm* 436: 359– 378.

Bruno, P. 1981. "A New Spectrophotometric Method for Determination of Vitamin B12 as Cobalts." *Analytical Letters* 14, (18): 1493-1500.

Chen, L., Subirade, M. 2006. "Alginate–whey protein granular microspheres as oral delivery vehicles for bioactive compounds." *Biomaterials* 27 : 4646–4654.

Cheong, A M, C P Tan, and K L Nyam. 2016. "In-vitro gastrointestinal digestion of kenaf seed oil-in-water nanoemulsions." *Indinia Crops Production* 87: 1-8.

Ching, Su Hung , Nidhi Bansal , and Bhesh Bhandari. 2017. "Alginate gel particles–A review of production techniques and physical properties." *Critical Reviews in Food Science and Nutrition* 57 (6): 1133-1152.

Dash, S, P N Murthy, L Nath, and P Chowdhury. 2010. "Kinetic modeling on drug release from controlled drug delivery systems." *Acta Pol Pharm* 67: 217-223.

Déat-Lainéa, E, V Hoffarta, J M Cardota, M Subiradeb, and E Beyssaca. 2012. "Development and in vitro characterization of insulin loaded whey protein and alginate microparticles,. 439 (2012) ." *International Journal of Pharmaceutical* 439: 136–144.

Fani, A A, R S Fortuny, and O M Belloso. 2017. "Nanoemulsions as edible coatings." *Current Opinion Food Science* 15: 43-49.

Ghasemi, Jahanbakhsh , and Bahman Abbasi. 2005. "Simultaneous Spectrophotometric Determination of Group B Vitamins Using Parallel Factor Analysis: PARAFAC." *Journal of the Chinese Chemical Society* 52: 1123-1129.

Ghorbanzade, T, S M Jafari, S Akhavan, and R Hadavi. 2017. "Nano-encapsulation of fish oil in nano-liposomes and its application in fortification of yogurt." *Food Chemistry* 216: 146-152.

Jafari, S M. 2017. *Nanoencapsulation of food bioactive ingredients.* Elsevier.

—. 2017. *Nanoencapsulation technologies for the food and nutraceutical industries.* Elsevier.

Khateeb , Mouhammed , Basheer Elias, and Fatema AL Rahal. 2015. "Validated Spectrophotometric Method to Assay of B6 and B3 Vitamins in Pharmaceutical Forms Using Potassium Iodide and Potassium Iodate." *International Letters of Chemistry, Physics and Astronomy* 60: 113-119.

Koutina, G, C A Ray, R Lametsch , and R Ipsen. 2018. "The effect of protein-to-alginate ratio on in vitro gastric digestion of nanoparticulated whey protein." *International Dairy Journal* 77: 10-18.

Lamas, M C, C Bregni, M D Aquino, J Degrossi, and R Firenstein. 2001. "Calcium Alginate Microspheres of Bacillus subtilis." *Drug Dev, Ind. Pharm* 27: 825–829.

LeBlanc, J G, J E Lain, M Juarez del Valle, V Vannini, D van Sinderen, M P Taranto, G Font de Valaz, G Savoy de Giori , and F Sesma. 2011. "B-Group vitamin production by lactic acid bacteria – current knowledge and potential applications." *Journal of Applied Microbiology* 111: 1297-1309.

Leon , A M, W T Medina, D J Park, and J M Aguilera. 2016. "Mechanical properties of whey protein/Na alginate gel microparticles." *Journal of Food Engineering* 188: 1-7.

Leon, Alicia M , Wenceslao T Medina, Dong J Park , and Jose´ M Aguilera. 2018. "Properties of microparticles from a whey protein isolate/alginate emulsion gel." *Food Science and Technology International 0(0) 1–10* accepted: 1-10.

McClements, D J. 2015. "Encapsulation, protection, and release of hydrophilic active components: Potential and limitations of colloidal delivery systems." *Advances in Colloid and Interface Science* 219: 27-53.

McClements, D J. 2004. "Protein-stabilized emulsions." *Current Opinon Colloid Interface Science* 9: 305-311.

Molina, V C, M Medici, M P Taranto, Font de Valdez, and G Font de Valdez. 2009. "Lactobacillus reuteri CRL 1098 prevents side effects produced by a nutritional vitamin B deficiency." *Journal of Applied Microbiology* 106: 467–473.

Moll, Rachel, and Bernard Davis. 2017. "Iron, vitamin B12 and folate." *Medicine* 45 (4): 198-203.

Moschona, Alexandra , and Maria Liakopoulou-Kyriakides. 2018. "Encapsulation of biological active phenolic compounds extracted from wine wastes in alginate-chitosan microbeads." *Journal of Microencapsulation* accepted: 1-36.

Ni, Y, L Wen, L Wang, Y Dang, P Zhou, and L Liang. 2015. "Effect of temperature, calcium and protein concentration on aggregation of whey protein isolate: Formation of gellike micro-particles." *International Dairy Journal* 51: 8–15.

Nwanisobi , G C, and P O Ukoha. 2016. "Spectrophotometric Determination of Niacin Using 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone." *Asian Journal of Chemistry* 28 (11): 2371-2374.

Oehlke, K, M Adamiuk, D Behsnilian, V Graf, E Mayer-Miebach, E Walz, and R Greiner. 2014. "Potential bioavailability enhancement of bioactive compounds using food-grade engineered nanomaterials: a review of the existing evidence." *Food & Function* 5 (7): 1341-1359.

Walash, M I, M Rizk, Z A Sheribah, and M M Salim. 2008. "Kinetic Spectrophotometric Determination of Biotin in Pharmaceutical Preparations." *International journal of Biomedical science* 4 (3): 238-244.

Wichchukit, S, M H Oztop, M J McCarthy, and K L McCarthy. 2013. "Whey protein/alginate beads as carriers of a bioactive component." *Food Hydrocolloids* 33: 66-73.

Zandi , M, N Dardmeh, S Pirsa, and H Almasi. 2017. "Identification of Cardamom Encapsulated Alginate–Whey Protein Concentrates Microcapsule Release Kinetics and Mechanism during Storage, Stew Process and Oral Consumption." *Journal of Food Process Engineering* 40 (1): 1-9.

Zandi, M., Mohebbi, M. 2015. "An agent-based simulation of a release process for encapsulated flavor using NetLogo platform." *Flavor and Fragnace Journal* 30: 224–229.

Zandi, M., Mohebbi, M. 2014. "Investigation of encapsulated diacetyl colloidosome release profile as a function of sintering process and release media properties." *Flavor and Fragnace Journal* 29 (6): 364-370.

Zandi, M., Mohebbi, M., Varidi, M., Ramezanian, N. 2014. "Evaluation of diacetyl encapsulated alginate-whey protein microspheres release kinetics and mechanism at simulated mouth conditions." *Food Research International journal* 56: 211-217.

Zandi, M., Pirsa, S., Dardmeh, N. 2017. "Simulation of ascorbic acid release from alginate-whey protein concentrates microspheres at the simulated gastro-intestinal condition using NetLogo platform." *Journal of Food Process Engineering* 40 (1): 1-9.

Zandi, Mohsen. 2017. "Evaluation of the kinetics of ascorbic acid (aa) release from alginate-whey protein concentrates (al-wpc) microspheres at the simulated gastro–intestinal condition." *Journal of Food Process Engineering* 40 (1): 1-11.

Zhang, Z, R Zhang, L Chen, Q Tong, and D J McClements. 2015. "Designing hydrogel particles for controlled or targeted release of lipophilic bioactive agents in the gastrointestinal tract." *European Polymer Journal* 72: 698-716.

Zhang, Zipei , Ruojie Zhang, Liqiang Zou, and David Julian McClements. 2016. "Protein encapsulation in alginate hydrogel beads: Effect of pH on microgel stability, protein retention and protein release." *Food Hydrocolloids* Accepted: 1-30.

Zhang, Y, Q C Wang, H Yu, J Zhu, K de Lange, Y Yin, Q Wang, and J Gong. 2016. "Evaluation of alginate–whey protein microcapsules for intestinal delivery of lipophilic compounds in pigs." *Journal of Science Food and Agricultur* 96: 2674–2681.

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جلد 16، شماره 3، مرداد - شهریور 1399، ص. 50-37

محافظت ویتامین از شرایط سیستم گوارش با استفاده از میکروژل آلژینات- پروتئین آب پنیر. مطالعه موردی ویتامین B کمپلکس

محسن زندی*

تاریخ دریافت: 1397/12/04
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چکیده

کمبود ویتامین اخیراً در برخی از کشورها به سبب رژیم غذایی نامتعادل یا ناقص وجود دارد، از این‌رو غنی‌سازی مواد غذایی با ویتامین ضروری می‌باشد. محافظت ویتامین در میکروژل سبب افزایش پایداری و زیست فراهمی عوامل فعال در برابر شرایط سیستم گوارش می‌گردد. هدف تحقیق اخیر تعیین، مقایسه و توسعه سیستم تحویل ایده‌آل به‌منظور محافظت ویتامین در برابر شرایط گوارش می‌باشد. برای این منظور، میکروژل آلژینات- پروتئین آب پنیر حاوی ویتامین به‌عنوان حامل بیوپلیمری ایجاد و توسعه یافت. این میکروکپسول از منظر مورفولوژی، اندازه‌گیری پتانسیل زتا، اندازه‌گیری توزیع اندازه ذرات، راندمان انکپسولاسیون و تحویل و در نهایت هضم در شرایط روده و معده آزمایشگاهی مورد آزمایش قرار گرفت. روش جذب برای کنترل رهایش ویتامین B در شرایط معده در طول مدت آزادسازی مورد استفاده قرار گرفت. آزمون‌های رهایش ویژگی‌های مفیدی را برای این نوع میکروکپسول مشخص نمود. مکانیسم رهایش با استفاده از مدل‌های سینتیکی پیش‌بینی گردید. نتایج نشاندهنده این بود که اکثر میکروکپسول‌ها به‌صورت کروی با اندازه 100 میکرومتر می‌باشد و این میکروکپسول‌ها به‌ترتیب دارای پایداری بسیار خوب و متوسط در شرایط معده و روده هستند. نتایج همچنین نشان داد که بیشترین میزان رهایش در شرایط معده- روده رخ داده و نوع ویتامین تاثیر اندکی بر میزان رهایش و پروفایل رهایش دارد. مدل‌های سنتیکی پیشنهاد می‌دهد که رهایش ویتامین‌های خانواده B عمدتاً با مکانیسم فیک دیفوزیون رخ می‌دهد. به‌طور کلی، این تحقیق نشان داد که میکروژل آلژینات- پروتئین آب پنیر حاوی ویتامین می‌تواند ویتامین را در برابر هضم معدوی محافظت نموده و به‌عنوان سیستم تحویل استفاده گردد.

واژه‌های کلیدی: ویتامین B کمپلکس، رهایش کنترل شده، میکروژل، پروتئین آب پنیر، آلژینات

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Research Full Papers

Impact of microwave-grill-drying (MWGD) on functional properties of berry Russian olive (*Elaeagnus angustifolia* L.)

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Abstract

Impact of microwave-grill -drying (MWGD) at different powers (300, 450 and 600 Watts) on functional properties of berry "Russian olive" was investigated. The effect of microwave's water and oil holding capacities, gelation, foaming and emulsifying, which will provide novel and applicable knowledge for the food industry, was determined. We specifically focused the kinetics drying. By increasing microwave -grill powers (300–600W), drying time decreased from 270 to 120 s. For dried Russain olive berry at each applied microwave-grill power, water holding capacity values were higher than oil holding capacity values. However, drying at 450W is the best method of retention of functional properties of fresh fruit of *E.angustifolia L.*

Keywords: *E.angustifolia* L., Power, Microwave-grill drying, Functional properties.

Introduction

Oleaster *(Elaeagnus angustifolia L.*) is a tree, and its fruit grows in various climatic and environmental conditions. It is also known as Russian olive, and native to western and central Asia, from southern Russia and Mediterranean environment (Anonymous, 2014).

The main *Elaeagnus* species in Algeria, Russian olive (*Elaeagnus angustifolia L.*), commonly called "Jijibe", grows spontaneously and it is located mainly in the highlands. It was introduced and planted in the regions of Djelfa, Biskra, Relizane, Mascara and South Tennes and Cherchell (Journal of Agriculture, 1958).

The fruits are valuable intems of health and can be used as natural antioxidants (Durmaz, 2012), natural colors. Also, they are being used in the fields of medicine and pharmacy in both Asia and in Europe with legal certifications (Gulcu and Celik Uysal, 2010).

There are no toxic substances in oleaster fruits. Oleasteris is advised to be consumed by the people who have kidney disorders. It can be used as a diuretic and fever-reducing drug (Baytop, 1984), for preventing intestine disorders and mouth rust, and its fruit extract can be used as anti-inflammatory and analgesic (Ahmedianiet *al.*, 2000) in traditional medicine. The oleaster fruit contains 12.33% protein (Akbolat et *al.*, 2008), vitamins (tocopherol, carotene, vitamin C, and thiamine), mineral substances (calcium, magnesium, potassium, iron, and manganese; Boudraa et *al.*, 2010). Dominant sugars in the plant are fructose and glucose (Ayaz and Bertoft, 2001). The size of the fruit is the same as olives and skin is hard, yellowish-brown in color.

Drying is the oldest and most popular preservation method for food and agricultural products. The fundamental concept of drying is to trim down moisture of products to a level, which will stop microbiological growth and keep the product's nutritive value and bioactive compounds in considerably higher levels (Kwok et *al.*, 2004; Changrue, 2006). Several drying methods have been developed in order to preserve different kinds of food materials

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because of myriad environmental, energy efficiency and economic concerns. Besides, all methods have something in common; the heat is applied by conduction, convection, radiation.

In order to prevent quality damage due to long drying time, microwave grill drying has been recently introduced. Microwave heating is a sort of dielectric heating, which uses electromagnetic radiation in the frequency ranging from 300 MHz to 300 GHz. According to Changrue (2006), the decrement of drying time due to volumetric heating of dielectric material increase the use of the microwave as a source of thermal energy.

Although studies have focused on the drying kinetics of *Elaeagnus angustifolia L.*, the lack of published work on the effect of microwave grill drying at different power levels on functional properties (protein solubility, water and oil absorption capacity, emulsifying and foaming properties, density, viscosity and gelation) of Russian olive explains the interest for the present work.

Materials and methods

Fruit collections

Healthy mature hawthorn (*Elaeagnus angustifolia* L.*)* fruits were harvested between October-November (2018) in North-West Algeria. Russian olive had an initial moisture content of percentage-wet basis, which was determined by drying in a convective oven (Memmert DO 6836, Germany) at 103±1°C for 24 h (Anon, 1995). The fruit was conserved at -20 °C until used. Russian olive was sorted. After that, the total quantity was divided into three batches, one for each process Microwave grill drying.

Drying methods

Microwave- grill drying

The drying apparatus used in this study consisted of a laboratory microwave grill oven (GE107Y, SAMSUNG Electronics) with technical features of 230 V, 50 Hz with a frequency of 2,450 MHz. The dimension of the microwave cavity was 335 mm × 330 mm × 195 mm. Drying trials were carried out at different microwave generation powers 30, 450 and 600W. Drying was performer per cycle (30 sec ON / 30 sec OFF); each cycle corresponds to the application of microwaves for a given 30-sec power and 30-sec power off. At the end of each cycle, the products are weighed on a scale of precession model: GL-300. The drying kinetics was thus determined by the evolution of the mass of the products after each cycle.

Drying was carried out until the moisture content of 10 % w.b. was reached; the mass of the material was recorded continuously during drying with the accuracy of ±0.1 g. Using the equation below it can be determined the variation of the dry base moisture content (X) versus time (S).

$$X = \frac{Ww - Wd}{Wd} \quad (1)$$

X: Moisture content on a dry basis (kg H_2O/ kg dry matter)

Ww: Weight of the sample on a wet basis (g)

Wd: Weight of dry matter of the sample (g)

In the MWGD, Russian olive was placed inside the MWGD oven. For all the power levels studied, samples (5± 0.5 g) were taken from the MWGD oven every 120 Sec for 600 W, up to 180 Sec for 450 W, and up to 270 Sec for 300 W. The total drying time was determined as the passing time until no discernible weight change for each sample was observed in each MWGD power level.

Given the heterogeneity of the microwave heating, the average of ten repetitions for each power was recorded.

The drying process was performed in three independent repetitions. The fruit was kept at −20 °C and ready for further analysis.

Functional properties analyses

Water and oil absorption capacity

Measurements of water and oil retention capacity are performed according to the method of Phillips et *al.* (1988). 1g of the dried Russian olive is mixed (m0) in 10 ml of water or oil and the whole was mechanically stirred for 30 min using a stirrer. The mixture was then centrifuged at 4500 rpm/ min for 30 min in a centrifuge (Model: SIGMA 3K20). The pellet after centrifugation is weighed (m1), but for measuring the water retention capacity, it is first dried at 105°C in an oven for 8 h (m2). The water retention capacity (WAC) and oilretention capacity (OAC) is calculated by the following formulas:

$$\text{WAC}(\%) = \frac{m2 - m1}{m1} \times 100 \qquad (2)$$

(WAC) was expressed asgwater pound by 100 grams materials.

$$\text{OAC}(\%) = \frac{m1 - m0}{m0} \times 100 \qquad (3)$$

(OAC) was expressed as g oil pound by 100 grams materials.

Solubility properties

0.1 g of the dried Russian olives were placed into a centrifugal tube (known weight) then dissolved with 10ml of 1% acetic acid for 30 min, using an incubator shaker operating at 240 rpm and 25^{O}C. The solution was then immersed ina boiling water bath for 10 minutes, cooled to room temperature and centrifuged at 10.000 rpm for10min.The supernatant was decanted. The undissolved particles were washed in distilled water (25ml) then centrifuged at 10.000 rpm. The supernatant was removed and undissolved pellets dried at 60^{O}C for 24hr. Finally, the particles were weighed and the percentage of solubility was determined (Fernandez-Kim, 2004).

$$\text{solubility}(\%) = \frac{iw - fw}{iw} \times 100 \qquad (4)$$

iw: Initial weight of the sample(g)
fw: Final weight of the sample (g)

Emulsion activity (EA) and emulsion stability (ES)

Emulsifying gactivity and stability were determined using the method reported by Neto et al. (2001). Five milliliters portion of dried Russian olive dispersion in water (10 mg·ml^{-1}) was homogenized with 5ml oil for 1min. The emulsions were centrifuged at 1100g for 5 min. The height of emulsified layer and that of the total contents in the tube was measured. The emulsifying activity was calculated as:

$$\text{Emulsifying property}(\%) = \frac{h1}{h2} \times 100 \qquad (5)$$

h1: height of emulsified layer in the tube (ml)
h2: height of total content in the tube (ml)

Emulsion stability (ES) was measured by recentrifugation followed by heating at 80°C for 30 minutes and subsequently cooled to 15°C. After centrifugation, the emulsified poured into 50 ml measuring cylinders and stay a few minutes until the emulsified layer was stable. ES was expressed as the percent of the total volume remaining emulsified after heating.

$$\text{Emulsifying stability}(\%) = \frac{h1}{h2} \qquad (6)$$

h1: height of emulsified layer heating (ml)
h2: height of emulsified layer before heating (ml)

Foaming properties

Foam capacity (FC) and foam stability (FS)

The method of Coffman and Garcia (1977) was used for the determination of the foaming capacity and stability of dried Russian olive. A weighed amount of flour is dispersed in 100 ml distilled water, after which the suspension was whipped vigorously for 2 min using a Phillips kitchen blender set at speed 2. Volumes were recorded before and after whipping. FC was expressed as the percentage increase involume. After 30 min, the volume of foam was measured and expressed as FS.

$$FC = \frac{Volumeafterwhipping - Volumebeforewhipping x\ 100}{Volumebeforewhipping} \qquad (7)$$

$$FS = \frac{foamvolumeaftertime\ (t) x\ 100}{Initialfoamvolume} \qquad (8)$$

Viscosity

Rheology studies the phenomena of deformation and flow of solids and fluids under the influence of mechanical forces. Viscosity characterizes the resistance to flow.

Viscosities of fresh, dried fruit extracts were determined
using a Gemini 150 digital Rheometer; three pascal-second reads (mPa • s) were taken per sample and recorded on the computer.

pH

1g of the dried Russian olive is homogenized in 3 ml of distilled water. The pH of the solution obtained was determined using a pH-meter (Model: HANNA HI 2210) (AFNOR NF V 50-108).

TSS Measurement of the refractometric index (°Brix)

The percentage of soluble solids was determined using a refractometer. The separation limit, between the light and dark areas on the scale of the refractometer, indicates the refractive magnitude of the light, which is a function of the percentage of soluble dry matter contained in the extracts, called refractometric refractive index (IR) (Refracto 30PX) or Brix degree (AFNOR NF V 50-109).

Gelation properties

Gelation properties were studied by employing the method of Coffman and Garcia (1977). Sample suspensions of 2 – 20% were prepared in distilled water. Ten milliliters of each of the prepared dispersions was transferred into a test tube. The test tubes were heated in a boiling water bath for 1 h, after which they were cooled in a bath of cold water. The test tubes were further cooled at 4°C for 2 hr. The least gelation concentration was taken as the concentration when the sample from an inverted test tube did not fall or slip.

$$\text{Gelation properties} = \frac{h1}{h2} \times 100 \qquad (9)$$

h1: height of gelation layer in the tube (ml)
h2: height of the total content in the tube (ml)

Statistical analysis

The experimental data were expressed as means± standard deviations. All determinations were carried out in triplicates. A statistical analysis of the results was performed using the 2009 XLStat software. An equal average hypothesis was tested by analysis of variance (ANOVA). The medium was significantly different when compared with the method of Newman-Keuls ($p \leq 0.05$).

Results and discussion

Moisture

The samples moisture content changed between 15.20 and 23.14 %. These results were similar to dried fruits, such as fig (30.00 %), prune (30.92 %), cranberry (16.00 %) and apricot (30.89 %) (Cansev et *al.*, 2011). This low water content results in the low water activity and low of biochemical and microbiological chemical alterations. These fruits have the advantage of being easily preserved, so they can be consumed for several months and thus be used for industrial purposes.

Drying Kinetics

Microwave grill drying Kinetics

The variations of the water content (X) versus time (S) for three powers of the microwave grill oven are shown in Figure1. A regular decrease in resulted curves can be seen.which is due to the high evaporation of free water existed in all samples.

The drying time was reduced with increasing power and energy delivered by the microwave grill. The power of 600 W showed the shortest time (120 Sec).

Obviously, drying time reduced with the increasing microwave drying power levels from 300 W to 450 W and lastly to 600 W. According to figure 1, the time required to reduce the moisture content of the Russian olive stem from 1 kg H_2O/kg dry solid to 0.2 kg H_2O/kg dry solid varied between 120 Sec to 270Sec subjected to the microwave grill power level.

At the beginning, the water content is important, which results in an acceleration of evaporation of water under the heating of the samples by the microwave rays and convection.

Trade is less important as drying takes place because the amount of water remaining in the product is low and difficult to remove.

The observed drastic or sudden drying curve at the initial stages of microwave drying may be triggered by the opening of the sample's structure physically which allowing rapid vaporization and passage of water molecules (Kostaropoulos and Saravacos, 1995).

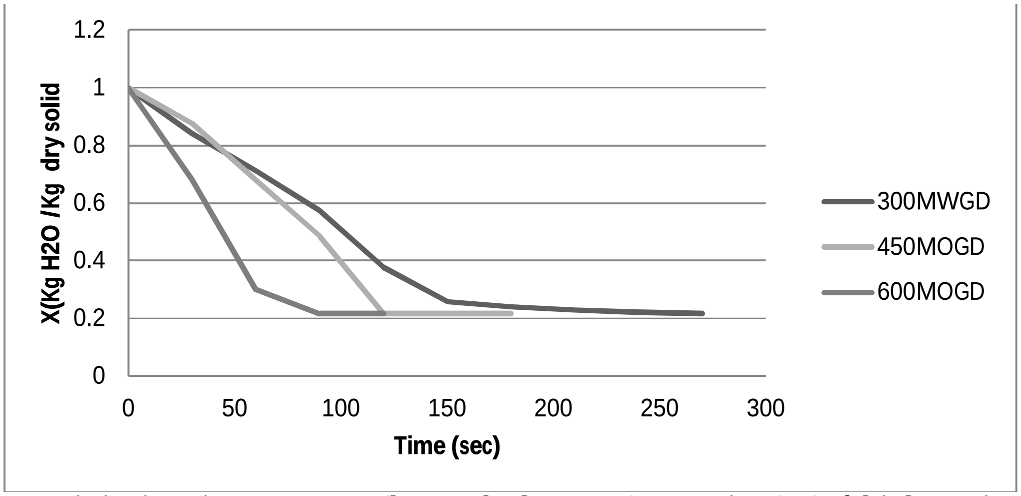

Figure 1. Variation in moisture content X (kg H_2O/ kg dry matter) versus time (sec) of dried Russain olive in microwave grill at different power.

Effect microwave-grill drying on the functional properties of Russain olive pulp

Water and oil absorption capacity

Water and oil absorption capacity are very important in the food system because of their effects on the flavorand texture of foods. As shown in Table 1.

Water and oil absorption capacity of the Russain olives samples ranged (203.06±6.00% and 256.23± 5.00%, microwaved grill at 300 and 600 W. Subjection of Russian olives to microwave reduced the water and oil capacity. Water absorption capacity is relevant in ensuring that food products possess good texture, which invariably reduces retrogradation and syneresis during storage, retorting and freezing (Odedeji and Adeleke, 2010). Oil absorption capacity is useful in food preparations that involve like bakery products where oil is an important ingredient (Princewill-Ogbonna and Ezembaukwu, 2015).

Robertson and Eastwood (1981) suggested that WAC is considered to be a function of fiber structure rather than a chemical composition. The power levels of microwave grill drying were reported to affect the fiber structure, which is related to the changes in a water absorption capacity. They reported the water absorption capacityis increasing from 300 W to 600 W (203.06± 6.00%, 236.12± 0.30%, and 256.23± 5.00% respectively), while their dietary fiber contents were only slightly different. They also observed the compression of cellular appearance in MWG-dried sample at 600W.

Sangnark and Noomhorm, (2003) reported that particle size reduction of dietary fibers has been associated with a lower ability to retain water and a lower oil binding capacity. Lario et *al.*, (2004) reported that thehigh WHC of fiber concentrate could be usedas a functional ingredient to avoid syneresis, modification of texture and viscosity andreduce calories of food formulations.

The reduction of water absorption capacity by both treatments could be as a result of hydrothermal treatment which blocked the tissue pores, thereby hindering water slippage and retention.

From Table 1, it can be seen that the oil absorption capacity is inversely proportional to the water absorption capacity. This makes sense. The ability of water and oil retention to respond to the structure of protein and polysaccharide macromolecules; the interactions between the water and the constituents are established at the level of acid groups and amine groups present in the polysaccharides or at the level of the uncharged polar groups capable of forming hydrogen bonds with water, while the groups that are apolar in character Can contribute to the structure of the water inTheir environment. According to Cloutour (1995), heat treatments such as microwave -grill- drying can alter the polysaccharide and protein content and consequently the water and oil absorption capacity.

It was noted that the capacity of water retention is clearly higher than that of the oil. This could be explained by the abundance of the hydrophilic groups by adding to the hydrophobic groups, the Russain olive of which is rich in polysaccharides (pectins 1.43% and cellulose 3.92%) and low in lipid (0.55%) (Saadoudi, 2008; Ferhat, 2008).

Table 2.Gelation properties (%) of dried Russain olive in microwave grill at different power

Power (W)	Gelation Capacity					
	Concentrations (%)					
	2	**4**	**8**	**12**	**16**	**20**
Fresh	13 .63±0.03^{s}	18.18±0.01^{r}	36.36±0.01^{k}	54.74±0.01^{e}	81.71±0.01^{b}	100±0.00^{a}
300	28.81±0.01^{o}	30,72±0.01^{n}	46.36±0.01^{j}	54.45±0.01^{g}	72.09±0.01^{d}	100±0.00^{a}
450	27.27±0.00^{q}	31.2±0.01^{m}	48.81±0.01^{i}	54/45±0.01^{g}	72.09±0.01^{d}	100±0.00^{a}
600	28.18±0.01^{p}	33.18±0.01^{l}	50.36±0.01^{h}	56.45±0.01^{f}	79.43±0.01^{c}	80±0.00^{b}

a, b, c, d…: In each column, means followed by a different letter are significantly different at the threshold of $P < 0.05$ (**Method of Newman and Keuls**).

Solubility

Solubility is an important characteristic for powdered ingredients that will be incorporated into dry mixes that must be reconstituted. To satisfy the normality assumption during the statistical analysis. The average solubility values for the Russain olive powder is Table 1. The samples dried by microwave-grill at 300 W had the highest average percentage of solubility (66± 0 .11 %).

In general, Russian olive components such as pectin and sugars are soluble in water, while proteins and lipids are readily soluble in acidic solutions diluted below pH 6 (pH4), which explains the use of Acetic acid in this technique (a 1% acetic solution is equivalent to pH 4).

According to table 1, the solubility of dried by microwave grill at different powers is acceptable without significant difference (≥50%). The solubility of the macromolecules is influenced by several parameters (pH, ionic strength, drying, concentration, temperature, etc.).

Linden and Lorient. (1994) show that the property of solubility has major consequences on other functional properties (Emulsification, gelling ...). On the other hand, depending on the results obtained, the microwave grill drying does not have a negative effect; On the other hand, it retains this property. As a result, the other properties will be more or less conserved.

Emulsifying properties and emulsion stability

Table 1 shows the emulsifying capacity and the stability of emulsions Russain olive dried by microwave grill at different powers. Good capacity is observed for all samples (over 30%). Precisely the best capacity is given for the power 300W (62.32± 0.01%).

Drying by microwave grill at different power (300,450 and 600 W) decreased caused significant ($p<0.05$) decrease in emulsion capacity of Russain olive berry when compared with the non-dried (control) samples.Drying by microwave grill at different power (300,450 and 600 W) decreased emulsion capacity Russain olive berry. The decrease in emulsion property may be attributed to protein aggregation as well as surface hydrophobicity and change the characteristics, which affect emulsifying properties in different ways (Cheftel *et al.*, 1985).

Firstly these results show that the applied power has an effect on this property, a moderate assay power (300W) is sufficient to have a good emulsion. On the other hand drying by microwave, the grill does not have a dramatic effect negative vis-à-vis the emulsifying capacity.Drying by microwave grill at different power (300,450 and 600 W) decreased emulsion capacity Russain olive berry.

Emulsion capacity denotes the maximum amount of oil that can be emulsified by protein dispersion. The high emulsion capacity could be as a result of high content of free fatty acid which leads to increased oil absorption (Ihekoronye and Ngoddy, 1985).

The emulsifying properties are due to the reduction of inter-facial trying among the hydrophilic groups are hydrophobic groups, they are often linked to the protein solubility in water (Roudot, 2002; Chandi and Sogi, 2006). According to Table 1 excellent emulsion stability can be seen (> 60%) for all dried Russain olive by microwave grill at different powers. nevertheless dried Russain olive at (600, 450 and 300 W respectively (60±0.09, 76.32± 0.00 and 64.61± 0.01%).

Foaming properties

The results gathered in Table 1 show that non-foam for Russain olive raw and dried by microwave grill at different powers. According to Lorient et *al.* (1988), the formation of foams is based on the presence of proteins in quantity and quality, thus the low Russain olive protein content (0.29%) (Abdeddaim, 2016) is insufficient to form stable foam. The shape, size, concentration, and hydrophobicity of the particles have been identified as the main factors in the formation of foams.

Viscosity

In general, the processdrying resulted in a decrease viscosity of Russain olive viscosity (Table 1).

In our study, the viscosity of Russain olive in microwave-grill at different power ranged from mPa.s 1.17 to 1.45 MPa.s. Viscosity, which is the desired parameter, is one of the qualities that characterize the flow behavior. It is a measure of the ability of the fluid to resist movement when shear stress is applied. All data show that viscosity generally decreases with drying techniques with increasing microwave grill power.

Significant changes in viscosity may be due to the significant impact of the process dryingon the biochemical composition Russain olive fruit. As also explained by Simas-Tosin et al (2010), the presence of oligosaccharides with free reducing functions, phenolic compounds and inorganic salts and polysaccharides in the structure of the Russain olive fruit. The effect of drying on the polysaccharide viscosity of Russain olive fruit could be due to the different proportions of soluble materials compared to insoluble materials.

pH

The average pH value of the raw berry Russian olive was 5.22 ± 0.00 which is within the acceptable range of pH (5.21-5.22) for Russians olive. The average pH values for the Russain olive powder dried using microwave-grill-dring at three different powers (300, 450 and 600 W) are shown in Table 1. Generally, the recorded pH is acid at the vicinity of 5; this is explained by the presence of free organic acids in the Russain olive (Sahan et al., 2015) such as malic acid (0.67 mg/ 100 g), oxalic acid (0.08 mg/ 100 g), ascorbic acid (0.08 mg/ 100 g),acetic acid (0.52 mg /100 g), citric acid (0.59 mg /100 g), tartric acid (0.52 mg /100 g) and formic acid (0.05 mg /100 g) .

Total soluble solid (TSS)

Significant changes in TSS after microwave drying were obtained due to variation power level. Decreased moisture content in fruits is generally accompanied by an increased percentage of TSS since TSS is the main component of dry matter (Malundo et *al.* 1995). Thus, the value of TSS is significantly ($P<0.05$) decreased after drying (Table 1). This decrease was up to 21 expansionl ower compared to fresh fruit (42.4 Brix°). Although there is a significant difference in the TSS value between the drying power levels, the value decreased with increasing power 300 W (1.17 Brix°), then increased to 450 W(1.45 Brix °) then decreased to 600 W (1.29 Brix°).

According to our results, we found that the temperature and the treatment time had no effect on pH and Brix°.

Gelation properties

The gelation concentration for Russain olive fruit raw and dried is shown in table 2. It formed a weak gel at 2 %, strong gel at 16 and 20% and very strong gel.

The least gelation capacity results for microwave grill at 300 W dried Russain olive is 2%, and microwaved grill at 600 W samples ranged from 12% to16%.The gel-forming ability is reported to be influenced by the nature of the protein in the sample as well as their interaction during heat treatment (Enujiugha et *al.*, 2003).

According to Table 2, the gelling power for the apple dried at 300 and 450 W and for the concentrations 16 and 20% is excellent it reaches 100%, these results are explained by the richness of Russain olive in (pectins 1.43% and cellulose 3.92%) (Saadoudi, 2008).

In general, the concentration expresses the percentage of the gelling agents (proteins, polysaccharides, etc.), a proportional increase in the gelling power with the increase of the concentration, the better is the gelating ability of the protein ingredient (Akintayo *et al.*, 1999). Variations in gelling properties may be ascribed to the ratios of different constituents, such as proteins, carbohydrates, and lipids.

Gelatinization influences the textural quality when powder of Russain olive fruit is incorporated in food products such as creams, soups, puddings, pie fillings and many sauces in viscosity.

Conclusions

Moreover, the kinetics of the dehydration of Russain olive fruit shows that microwave drying time is short in supply to other drying methods. This reveals the economic importance of dehydration by microwave of the fruits of the Russain olive.

In the drying process, power and long exposure time contribute significantly to the decreasing of emulsifying property content present in the Russain olive fruit. At 600W occurs its lowest decreasing.

The effect microwave–grill-drying at different level (300, 450 and 600 W) on the functional properties of Russain olive fruit has a relatively low water absorption capacity compared to Russain olive fruit raw. The higher functional properties of Russain olive fruit dried in a microwave–grill-drying at 450 W are very important.

These results showed the important role of this fruit in the food industry, such as the manufacture of beverages on the basis of solubility and its ability to retain water, the manufacture of jellies and creams for its ability it's related to emulsifying and gelling, and any other applications, especially in confectionery and pastry.

References

Abdeddaim, M. (2016).Etude de la composition biochimique des fruits de cinq espèces végétales présentes dans la région des aurès en vue de leur utilisation alimentaire ou pharmacologique (*celtis australis L, crataegus azarolus L, crataegus monogyna J, elaeagnus angustifolia L, et zizyphus lotus L)*.Thèse de doctorat .Université de Sétif, 174p.

AFNOR. (1982). Produits dérivés des fruits et légumes-jus de fruits. Détermination de pH, Association française de normalisation. (Ed). AFNOR, Paris, 325 p.

Ahmediani, A, Hosseiny.J and Semnanian, S.L. (2000) .Antinociceptive and anti-inflammatory effects of Elaeagnus angustifolia fruit extracts.*Journal of Ethnopharmacology, 72*, 287–292.

Akbolat, D., Ertekin, C., Menges, H.O., Guzel, E. and Ekinci, K. (2008) Physical and nutritional properties of oleaster (*Elaeagnus angustifolia L.*) growing in Turkey.*Asian Journal of Chemistry*, *20*,2358–2366

Akintayo, E.T., Oshodi A.A. and Esuoso, K.O.(1999). Effects of NaCl, ionic strength and pH on the foaming and gelation of pigeon pea (*Cajanus cajan*) protein concentrates. *Food Chemistry, 66*, 51-56.

Anon, (1995).Contrôle de qualité des products alimentaires, méthodes d'analyses officielles, AFNOR–DGCCRF, Paris, Fr, 416 p

Anonymous, (2014). *Elaeagnus angustifolia*. http://en.wikipedia.org/ wiki/n Elaeagnus_V angustifolia

Ayaz, F.A. and Bertoft, E. (2001). Sugar and phenolic acid composition of stored commercial oleaster fruits. *Journal of Food Composition and Analysis*, *14*, 505–511.

Baytop, T. (1984). Treatment with Plants in Turkey (Past and Present). Number: 40, Pp. 260. Istanbul, Turkey: Pharmacy Faculty, Istanbul University Publication Number: 3255.

Boudraa, S., Hambaba, L., Zidani, S. and Boudraa, H. (2010). Mineral and vitamin composition of fruits of five underexploited species in Algeria: *Celtis australis L., Crataegus azarolus L., Crataegus monogyna Jacq, Elaeagnus Angustifolia. And Zizyphus lotus L. Fruits*, *65*, 75–84.

Cansev, A., Sahan, Y., Celik, G., Taskesen, S. and Ozbey, H. (2011).Chemical properties and antioxidant capacity of Elaeagnus angustifolia L. fruits.*Asian Journal of Chemistry*, *23*, 2661–2665.

Chandi, G.K and Sogi, D.S. (2006). Functional properties of rice bran protein concentrate. *Journal of Food Engineering*, *79*,592-597.

Changrue, V. (*200*6). Hybrid *(*osmotic, microwave-vacuum*)* drying of strawberries and carrots. A *thesis* submitted to McGill University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Montreal, Quebec, Canada.

Cheftel, J. C., Cuq, J. L.and Lorient, D. (1985). Food Chemistry (2nded.), Marcel Dekker, New York.

Cloutour, F.(1995). Caractéristiques de fibres alimentaires: influence sur la fermentation in vitro par la flore digestive alimentaire. Thèse de doctorat, Université de Nantes, 123 p.

Coffman, C.W. and Garcia, V.V. (1977). Functional properties and amino acid content of protein isolate from mung bean flour. *Journal of Food Technology, 12*,473–484.

Durmaz, E. (2012). Microwave Extraction of Phenolic Compounds from Caper and Oleaster. Ankara, Turkey: Master of Science in Food Engineering Department, Middle East Technical University.

Enujiugha, V.N., Badejo, A.A., Iyiola, S.O. Oluwamukomi M.O. (2003). Effect of germination on the nutritional and functional properties of African oil bean (*Pentaclethra macrophylla Benth*) seed flour.*Journal Food Agriculure and Environnoment*, 1:72-75.

Ferhat, R. (2008). Étude de la fraction lipidique et la composition en acides gras des fruits de: *Celtis australus L., Crataegus azarolus L., Cratagus monogyna Jacq, Elaeagnus angustifolia L* et *Ziziphus lotus L*. Mémoire de Magister. Université El Hadj-Lakhder. Batna, 102p.

Fernandez-Kim, S-O. (2004). Physicochemical and functional properties of crawfish chitosan as affected by different processing protocols. Master Thesis of Science. Louisiana State University, 99p.

Gulcu, S. And Celik, Uysal, S. (2010). Kus igdesi'nde (Elaeagnus Angustifolia L.) yetistirme sıklıgının fidan morfolojik ozellikleri neetkisi.*SDU Faculty of Forestry Journal*, 2, 74–81.

Ihekoronye, A. I. and Ngoddy, P. O. (1985). Food Carbohydrates. In: Integrated Food Science and Technology for the tropics Macmillan publisher, London. pp 10 -19

Journal d'Agriculture Tropicale et de Botanique Appliquée. (1958). Les méthodes d'enquête en ethnobotanique: Comment mettre en évidence les taxonomies indigenes. Paris. 15(7-8), pp 297-324.

Kostaropoulos, A.E. and Saravacos, G.D. (1995). Microwave pretreatment for sun-dried raisins, *Journal of Food Sciences, 60*, 344-347.

Kwok, B.H.L., Hu, C., Durance, T. and Kitts, D.D. (2004). Dehydration Techniques Affect Phytochemical Contents and Free Radical Scavenging Activities of Saskatoon berries (*Amelanchier alnifolia Nutt*). *Journal of Food Science*, 69, 122-126.

Lario, Y., Sendra, E., García-Pérez, J., Fuentes, C., Sayas-Barberá, E., Fernández-López, J.and Perez-Alvarez, J.A. (2004). Preparation of high dietary fiber powder from lemon juice byproducts. *Innovative Food Sci. Emerging Technol. 5*, 113–117.

Linden, L. and Lorient, D. (1994). Biochimie agro- industrielle-Valorisation alimentaire de la production agricole. (ED) Masson. Paris. Milan. Barcelone, 359p.

Lorient, D., Colas, B. and Le meste, M. (1988). Propriétés fonctionnelles des macromolécules alimentaires. The notebooks of the ENS.BANA.N° 6. (ED) Tec and doc- Lavoisier. Paris, 268p.

Neto, V.Q., Narain, N., Silvia, J. B. and Bora, P. S. (2001). Functional properties of raw and heat-processed cashew nut (*Anarcardium occidentale* L.) kernel protein isolate. *Nahrung, 45,* 258–262.

Odedeji, J.O. and Adeleke, R. (2010). Pasting characteristics of wheat and sweet potato flour blends. *Pakistan Journal of Nutrition, 9(6)*, 555-557

Phillips, R. D., Chinnan, M. S., Branch, A. L., Miller, J. and Mc Watters K. H. (1988). Effects of pre-treatment on functional and nutritional properties of cowpea meal. *Journal of Food Science,* 53(3), 805-809.

Princewill-Ogbonna, I. and Ezembaukwu, N. (2015). Effect of various processing methods on the pasting and functional properties of Aerial yam (Dioscorea bulbifera) flour. *British Journal of Applied Science and Technology, 9(5),* 517-526.

Redout, A.C. (2002). Rhéologie et analyse de texture des aliments. (ED) Tec and Doc. Paris, 199p.

Robertson, J.A.and Eastwood, M.A. (1981). An examination of factors which may affect the water holding capacity of dietary fiber. *British Journal of Nutrition. 45,*83-88

Saadoudi, M. (2008). Etude de la fraction glucidique des fruits de *Celtis australus L., Crataegus azarolus L., Cratagus monogyna Jacq., Elaeagnus angustifolia L et Ziziphus lotus L.*Mémoire de Magister. Université El Hadj-Lakhder, Batna

Sahan, Y., Gocmen, D., Cansev, A., Celik, G., Aydin, D., Ayşe, N., Dilek, D., Dulger, H. Kaplan, B., Kilci, A.and Gucer, S.(2015).Chemical and techno-functional properties of flours from peeled and unpeeled oleaster (*Elaeagnus angustifolia L.*). *Journal of Applied Botany and Food Quality, 88,* 34 -41**.**

Sangnark, A. and Noomhorm, A. (2003). Effect of particle sizes on functional properties of dietary fiber prepared from sugarcane bagasse. *Food Chemistry. 80*, 221-229.

Simas-Tosin, F.F., Barraza, R.R., Petkowicz, C.L.O., Silveira, J.L.M., Sassaki, G.L., Santos, E.M.R., Gorin, P.A.J. and Iacomini, M., (2010). Rheological and structural characteristics of peach tree gum exudates.*Food Hydrocolloids*, *24,* 486

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تأثیر خشک کردن مایکروویو- گریل (MWGD) بر خصوصیات عملکردی زیتون روسی (*Elaeagnus angustifolia* L.)

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چکیده

در این پژوهش تاثیر خشک کردن به روش مایکروویو- گریل (MWGD) در میزان انرژی‌های مختلف (300، 450 و 600 وات) بر خصوصیات عملکردی "زیتون روسی" مورد بررسی قرار گرفت. همچنین اثر عوامل جدید و کاربردی در صنعت غذا مانند ظرفیت نگهداری آب و روغن توسط مایکروویو، تشکیل ژل، کف و امولسیون نیز با تمرکز بر خشک کردن سینتیکی مورد ارزیابی قرار گرفت. نتایج نشان داد با افزایش انرژی مایکروویو، زمان خشک کردن از 270 به 120 ثانیه کاهش می‌یابد. همچنین مشخص شد در خشک کردن زیتون روسی در هر میزان انرژی الکتریکی مایکروویو، ظرفیت آب بالاتر از روغن می‌باشد. بنابراین خشک کردن در 450 وات انرژی مایکرویو بهترین روش خشک کردن با حفظ خواص عملکردی میوه تازه *Elaeagnus angustifolia* L است.

واژه‌های کلیدی: *Elaeagnus angustifolia* L، انرژی، خشک کردن مایکروویو-گریل، خواص عملکردی

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Research Full Papers

Predicting the physiological characteristic changes in pears subjected to external loads using Artificial Neural Network (ANN)-Part 1: Static loading

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Abstract:
This research was aimed to study the effects of loading force and storage period on the physiological characteristic of pears. In this experiment, the pears were subjected to quasi-static loading (wide-edge and thin-edge) and different storage periods (5, 10 and 15 days). The amounts of the fruits' total phenol, antioxidant and vitamin C contents were evaluated after each storage period. In the present study, multilayer perceptron (MLP) artificial neural network featuring a hidden layer and two activating functions (hyperbolic tangent-sigmoid) and a total number of 5 and 10 neurons in each layer were selected for the loading force and storage period so that the amounts of the total phenol, antioxidants and vitamin C contents of the fruits could be forecasted. According to the obtained results, the highest R^2 rates for thin-edge and wide-edge loading in a network with 10 neurons in the hidden layer and a sigmoid activation function were obtained for total phenol content($R^2_{Thin\ edge}$=0.9539-$R^2_{Wide\ edge}$=0.9865), antioxidant ($R^2_{Thin\ sdge}$=0.9839-$R^2_{Wide\ edge}$=0.9649) and vitamin C ($R^2_{Wide\ edge}$=0.9758); as for wide-edge loading in a network with 5 neurons in the hidden layer and hyperbolic tangent activation function, the highest R^2 rate of vitamin C content was obtained equal to $R^2_{Wide\ edge}$=0.9865. According to the obtained results, the neural network with these two activation functions possesses an appropriate ability in overlapping and predicting the simulated data based on real data.

Keywords: Pears' internal contents, loading, storage, Neural Network, Activation function

Introduction

Pears have been recognized as sources of sugars, minerals, various ingredients (including vitamin C) and some phenolic compounds as well as natural antioxidants. The quality of pears is defined depending on their physical characteristics such as texture, size, color, and odor as well as chemical parameters such as sugar, organic acids, minerals and vitamins. These factors change subject to the type of the fruit, ripening level, cultivation and environmental conditions (Kazem et al., 2015) (Gurrieri et al., 2000). Although pears have abundant advantages, the reasons for lower uses of pears in respect to other fruits are relatively high prices and problems related to storage and quality of the pears. Pears respond to environmental conditions and these physical and chemical reactions of the harvested fruits cause drops in the quality of the products subject to various stresses and this causes wastages in the agricultural products. In addition, during storage, many factors might act as stressors as a result of which the fruits' useful life will be reduced (Galvis-Sánchez et al. 2004). On the other hand, external stresses such as falling down from the tree, compression during storage and so forth cause bruises in the pears and such a bruise in the fruit is created through the enzymatic oxidation of the phenolic

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ingredients, such as polyphenoloxidase, and the bruise level of the fruit depends on the nature and the amount of phenolic ingredients inside the fruits as well as the polyphenoloxidase activity. Plant phenols are easily oxidized by polyphenoloxidase which acts as a defending enzyme after a textural damage following which bruises appear on the fruits' surfaces (Malakouti et al., 2009).

The main reason for the reduction in marketability and quality of the agricultural products is the damage caused between harvesting and consumption. Fruits are prone to bruise during picking, packaging, transportation and retailing in the stores as well as during other stages and they are sensitive to damages caused through getting in contact with one another and/or being hit against a hard surface like ground and/or boxes. Although it has been made well clear that the bruise in the fruits is the result of extreme external forces on the fruit surface, it is yet to be clarified that what factors determine the difference in fruits' sensitivity to a given force (Yurtlu and Erdoğan, 2005). The artificial neural network is a topic discussed in artificial intelligence and it is an information processor trained using a percentage of input and output data and the system's performance method is stored in its memory (Mazloumzadeh et al., 2008). Artificial neural networks are trained based on the calculations on numerical data or examples. One feature of the neural networks is their ability in extracting the relationships between the inputs and outputs of a process with no need to complex environmental conditions. They are capable of connecting a multidimensional space to another space even if the information is imperfect and erroneous. These characteristics have made them appropriate for the problems related to the estimation and prediction in agriculture and industry and the neural network displays a good efficiency when the relations are nonlinear (Beale and Jackson, 1998; Menhaj, 2000). Various researchers have reported the use of ANN for evaluation and prediction of a combination of agricultural products:

Zarif Neshat et al (2013) have used bruise volume as a bruise damage index. They made use of radial basis ANN to evaluate the radial basis function model and regression model in predicting the bruise volume in apples. Their results indicated that the real and predicted values of bruise volume have been fit well with estimations of mean absolute percentage errors (MAPE) smaller than 2.82%. Their results also indicated that the radial basis function model enjoys a greater precision in comparison to regression model in predicting the apples' volume of a bruise (Zarifneshat et al., 2012).

An indicator of antioxidant capacity of sage in addition to moisture content, was added as an output of an optimized ANN using a multi-objective genetic algorithm and was presented by (Jebri et al., 2018).

The shrinkage of dried kiwifruit using digital images was modeled by Bai et al. (2018) while Nadian et al. (2015) modeled the color alterations of ginkgo biloba seeds along with drying kinetics of microwave drying and apple color changes during convection drying. It is evident than MLP ANNs can be applied for a range of agricultural products, describing accurately many properties of drying, as well as qualitative and quantitative indicators (Bai et al., 2018)(Nadian et al., 2015)(Chasiotis et al., 2019).

Torkashvand et al (2017) performed an experiment on the hardness and nutrient constituents of kiwi using multiple linear regressions (MLR) and artificial neural networks (ANNs) the results of which indicate that MLR model outperforms ANNs for Kiwi fruits in terms of precision (Torkashvand et al. 2017).

According to the fact that pears are very sensitive to impact and any stress on pears causes quality drops and that the pears have to be carefully handled during storage, the present study was aimed to investigate the data obtained from the experimenting and recognizing the ability of neural network in predicting the simulated data. Also, the overlapping and data sensitivity coefficients were studied.

Materials and methods

Sample preparation

Pears (Spadana variety) were purchased from the markets of Gorgan, Golestan province, Iran. Samples were taken to the laboratory of Gorgan University of Agricultural Sciences and Natural Resources. They were placed in an oven at 103℃ for 24 hours and their moisture contents were measured. The moisture content of the pears was calculated to be 77.92% (Azadbakht et al, 2019).

Quasi-Static test

To perform the wide and thin edge compression mechanical test, a pressure-deformation device (the Santam Indestrone - STM5-Made in Iran) with a load cell of 500 N was used. The compression test, where two circular plates were used, was performed at a speed of 5 mm/s with three forces of 70, 100, and 130 N and three repetitions. In this experiment, the pear samples were horizontally placed between the two plates and pressed, with the duration of the measurement recorded. Concerning thin edge compression test, we designed a double-jaw of plastic with a rectangular cross-section dimension of 0.3 × 1.5 cm. The test was performed at a speed of 5 mm/s with three forces of 15, 20, and 25 N and three repetitions (Fig. 1).

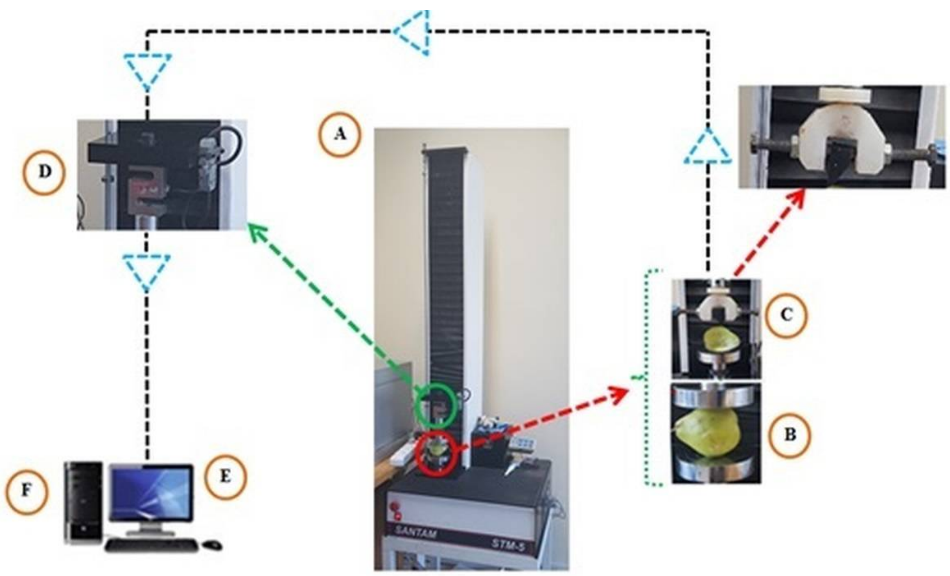


Fig. 1. Static quasi-load diagram of pear

A: The force-deformation device (Inestrone), B: Jaw wide edges C: Jaw thin edges D: Load Cell, E:Computer F: Information Extract

Vitamin C

Vitamin C amounts were calculated using 2,6-dichlorophenol indophenol titration method in such a manner that 5 grams of sample was mixed and extracted using 40 milliliters of citric acid 8% in the first stage. Afterwards, 10 ml of the filtered extract was picked up and mixed with 40 milliliters of citric acid 8% and subjected to titration using 2,6-dichlorophenol indophenol reagent. The termination point of titration was the appearance of a pale purple that lasted for about 15s. The vitamin C amount is expressed in milligram per 100 gram of the sample weight. vitamin C amount can be obtained by formula 1:(Tavarini et al., 2008)

$$\text{Vitamin C}=\frac{\text{sample weight}\times\text{standard volume of reagent consumed}}{\text{volume of extract obtained}\times\text{volume of reagent used}\times 10\times 2} \quad (1)$$

Biochemical properties measurement

To measure the total phenol content and the percentage of free radicals' neutralization, 0.5 gram of each sample pear was cut off and using 5 milliliters of methanol 80% (for a 1:10 ratio) in a cold mortar was homogenized. The homogenized mixture was placed on a shaker device in a dark room for 24 hours and then subjected to centrifugal force in 3000rpm for 5 minutes. The upper part of the extract was used for measuring the biochemical characteristics (Jaramillo-Flores et al., 2003) (Li et al., 2012).

Total phenol content

Folin-Ciocalteu (F-C) reaction was used to measure the total phenol content. To do so, 20 microliters of methanolic extract (0.5g in 5ml 80% methanol) was mixed with 100 microliters of F-C and 1.16ml of distilled water following which 300 microliters of 1molar sodium carbonate (10.6g in 100ml of distilled water) was added there after an 8-minute resting time. The aforesaid solution was placed in a vapor bath, 40°C, in a dark room for 30 minutes. In the end, the specimens were read in 765-nm wavelength. The absorption number of the specimen was replaced for y in the line equation to obtain the phenol amount (x) in milligram gallic acid per gram (Jaramillo-Flores et al., 2003).

Percentage of free radicals neutralization based on DPPH method

In this experiment, the percentage of DPPH free radicals' neutralization was measured based on the method proposed by Bandet et al (1997). At first, 2 milliliters of DPPH with a concentration of 0.1 millimoles (4 milligrams of DPPH in 100 milliliters of methanol) was mixed to the experiment tube and 2 milliliters of the prepared methanolic solution was next added following which the experiment tubes were placed in a dark environment and the absorption rates were immediately read using spectrophotometer in 517-nm wavelength. The evidence specimen contained 2 milliliters of DPPH and 2 milliliters of methanol. Methanol was applied to calibrate the spectrophotometer. The figures obtained from formula (2) substitutions were converted to neutralization percentages (Li et al., 2012).

$$DPPH = \frac{Ac-As}{Ac} \times 100 \quad (2)$$

As= specimens absorption rates

Ac= evidence specimen absorption rate

Artificial neural network modeling

In this research, the artificial multilayer perceptron (MLP) neural network was used for modeling the investigated pear components during storage and loading different components to predict total phenol content antioxidant and vitamin-C using one hidden layer and 5 and 10 neurons using the Neuro Solution 5 software. Hyperbolic tangent and sigmoid activation functions (Equation 3,4), which are the most common type of activation functions, were used in the hidden input and output layer. In this study, the Levenberg-Marquardt algorithm was used to learn the network (Taheri-Garavand et al., 2018). Additionally, 70% of the data were used for training, 10% of them were used for network evaluation (Validating Data), and 20% of the data were used for testing the network (Testing data) (Table 2). The loading value (27 data) and storage time (27 data) as network inputs of total phenol content antioxidant and vitamin-C (27 data for each component) were the considered network outputs (Figure. 2). Five repetitions were considered to achieve the minimum error rate and maximum network stability as a mean of 2000 Epoch for the network. The error was estimated using an algorithm with back propagation error. Statistical parameters including, Root Mean Square Error (RMSE), R^2, and Mean Absolute Error (MAE) were calculated for inputs and relationships were calculated using the formulas shown in Table 1.

Table 1- Neural Network Relationships

Formula	Formula Number	Reference
$\text{Tanh} = \frac{e^{x}-e^{-x}}{e^{x}+e^{-x}}$	(3)	(Soleimanzadeh et al., 2015)
$\text{Sig}=\frac{1}{1+e^{-x}}$	(4)	(Salehi et al., 2017)
$R^2 = 1- \frac{\sum_{i=1}^{n}(P_i-O_i)^2}{(P_i-O)^2}$	(5)	(Azadbakht et al., 2016)
$r = \sqrt{1-\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{(P_i-O)^2}}$	(6)	(Salehi and Razavi, 2012)
$\text{RMSE} = \sqrt{\sum_{i=1}^{n}\frac{(P_i-O_i)^2}{n}}$	(7)	B. Khoshnevisan, Sh.) (Rafiee, M. Omid, 2013
$\text{MAE} = \frac{\sum_{i=1}^{n}\lvert P_i-O_i\rvert}{n}$	(8)	(Azadbakht et al., 2017)

Table 2- Optimization values for artificial neural network parameters

Number of hidden layers	Learning rule	Type of activation function	The number of hidden layer neurons	Testing data %	Validating data %	Training data %
1	Levenberg Marquardt	Hyperbolic tangent and sigmoid	5	20%	10%	70%
1	Levenberg Marquardt	Hyperbolic tangent and sigmoid	10	20%	10%	70%

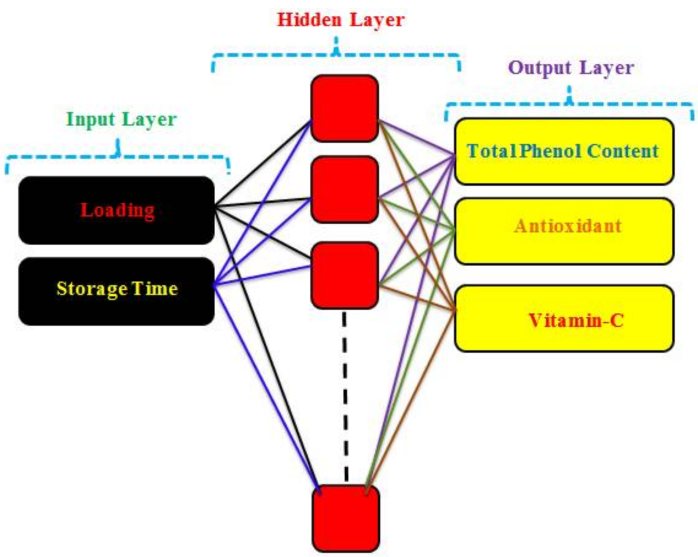


Fig. 2. Neural Network Input and Output Schematic

Results and discussion

Artificial neural network

As lower error value was obtained using the hyperbolic tangent and sigmoid activation function, this type of function was selected as the activation function in the hidden layer and the output. Based on the test method, 70% of the data were used for training and the network could learn the relationships between inputs and outputs well and 20 % of the data were used to test the network and 10 % of the data were used to cross validation network. The value of mean squared error, normalized mean squared error, mean absolute error and correlation coefficient are shown in tables 3 and 5.

Table 3- Error values for the quasi-static (thin edge) in predicting experimental data using optimal artificial neural network

	Activation function	Neuron number	MSE		RMSE		MAE		R^2	
			Training	Test	Training	Test	Training	Test	Training	Test
Total Phenol Content	hyperbolic tangent	5	1.7442	2.1133	1.320682	1.453719	1.2412	1.3638	0.9325	0.9259
		10	1.2475	0.5941	1.116915	0.770779	1.0058	0.6562	0.9335	0.9779
	Sigmoid	5	1.13868	1.224	1.209835	1.106345	0.93139	0.997	0.95307	0.796
		10	1.4637	1.3345	1.067089	1.155206	1.0343	1.085	0.9539	0.8811
Antioxidant	hyperbolic tangent	5	3.7115	9.3642	1.926525	3.060098	1.6048	2.7622	0.8988	0.9697
		10	1.2373	6.6489	1.11234	2.578546	0.9278	1.8905	0.9723	0.8610
	Sigmoid	5	3.71343	4.973	1.927026	2.230022	1.41926	1.577	0.93380	0.858
		10	0.7374	6.0616	0.85872	2.462032	0.7677	1.924	0.9839	0.8811
Vitamin-C	hyperbolic tangent	5	0.0440	0.0274	0.209762	0.165529	0.1687	0.1502	0.9389	0.9691
		10	0.0359	0.0356	0.189473	0.18868	0.1594	0.1459	0.9481	0.9362
	Sigmoid	5	0.03899	0.084	0.197459	0.289828	0.15294	0.245	0.95237	0.862
		10	0.0233	0.0305	0.152643	0.174642	0.1226	0.15	0.9758	0.9495

The quasi-static (thin edge)

The results showed that neural network has 10 neurons in the hidden layer and Sigmoid activation function for Total Phenol Content (R^2= 0.9539- RMSE=1.067089), Antioxidant (R^2= 0.9839- RMSE=1.11234) and vitamin-C (R^2= 0.9758- RMSE=0.152643) can predict Total Phenol Content Antioxidant and vitamin-C in different loading and storage time (table 3). In addition, the neural network with 5 neurons in the hidden layer and Sigmoid activation have the highest R^2 value, after the above-mentioned layers for Total Phenol Content and vitamin-C used. The highest value for antioxidant was showed in 10 neuron in hidden layer and function activation hyperbolic tangent. Lu et al.

used neural networks to estimate the losses of ascorbic acid, total phenols, flavonoid, and antioxidant activity in asparagus during thermal treatments, and concluded that the predicted values of the correlation coefficients between experimental and ANNs ranged from 0.8166 to 0.9868. Therefore, ANNs could be potential tools to predict nutrient losses in vegetables during thermal treatments (Lu et al., 2010).

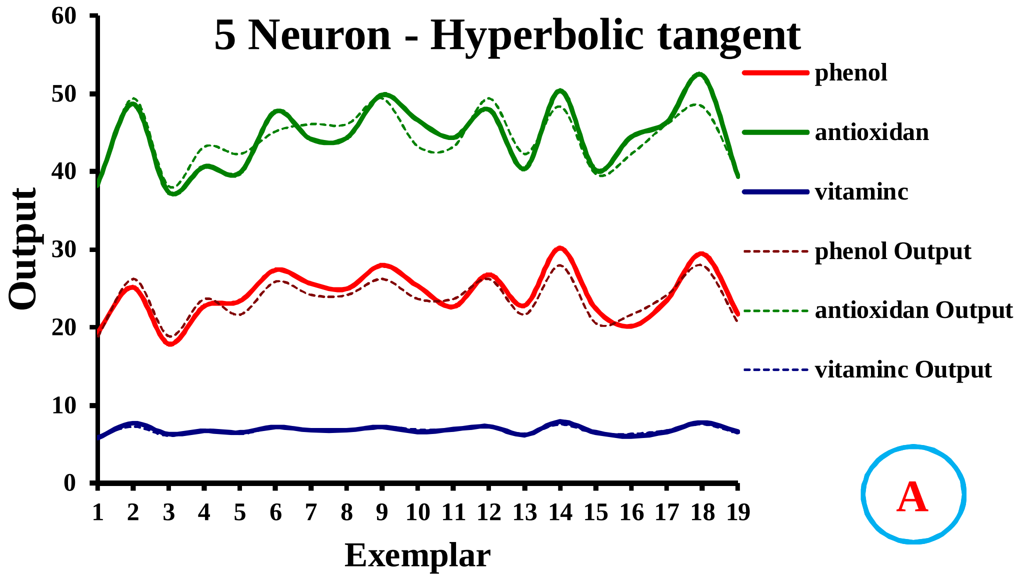
Also table 4 shows the best network between input data and data simulated by the network for each of the neurons in the hidden layer. The lower value of Epoch indicates that the number of neurons in the layer has been able to have learned from the neural network compared to an other number of neurons.

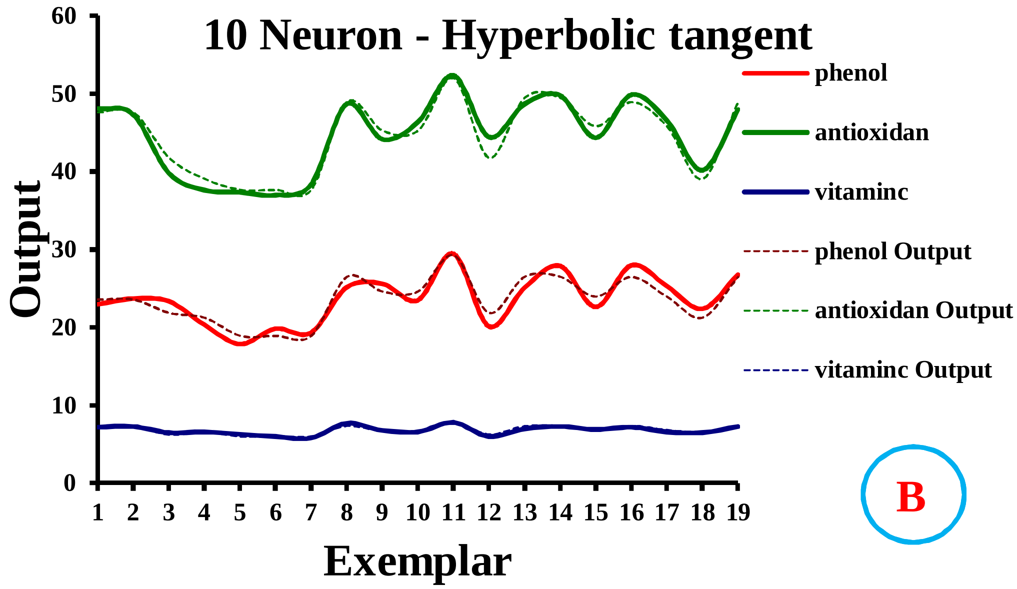
As shown in Table 4, the best network for Total Phenol Content at Training (Run= 1, Epoch = 19) in the 10-neuron state in the hidden layer and hyperbolic tangent activation reaches to constant value after about 19 Epoch of error, and the best network for Antioxidant Training (Run = 1, Epoch = 38) in 10-neuron state in the hidden layer and hyperbolic tangent activation. For vitamin-C of Training value (Run = 1, Epoch = 25), it was found in 5-neuron state in the hidden layer and hyperbolic tangent activation.

Table 4- Some of the best MLP neural network topologies to predict training values

	Activation function	Neuron number	Run		Epoch	
			Training	Cross Validation	Training	Cross Validation
Total Phenol Content	hyperbolic tangent	5	1	2	62	7
		10	1	4	19	11
	Sigmoid	5	1	5	28	22
		10	1	5	36	20
Antioxidant	hyperbolic tangent	5	1	1	69	15
		10	1	3	38	11
	Sigmoid	5	1	2	61	32
		10	1	4	38	6
Vitamin-C	hyperbolic tangent	5	1	4	25	8
		10	1	4	33	13
	Sigmoid	5	1	2	78	48
		10	1	5	45	16

Also, figure (3) illustrates the output amounts between the real and predicted data. Based on the figure (3), it can be observed that the neural network has been sufficiently capable of predicting and comparing the given numbers and it can be stated considering the closeness and similarity of the numbers outputted from the ANN to the real data that the neural network possesses an appropriate competency for data prediction. Moreover, considering the R^2 rates, the network with sigmoid activation function featuring 10 neurons in the hidden layer (figure 2-D) presents the best overlap with the real data.





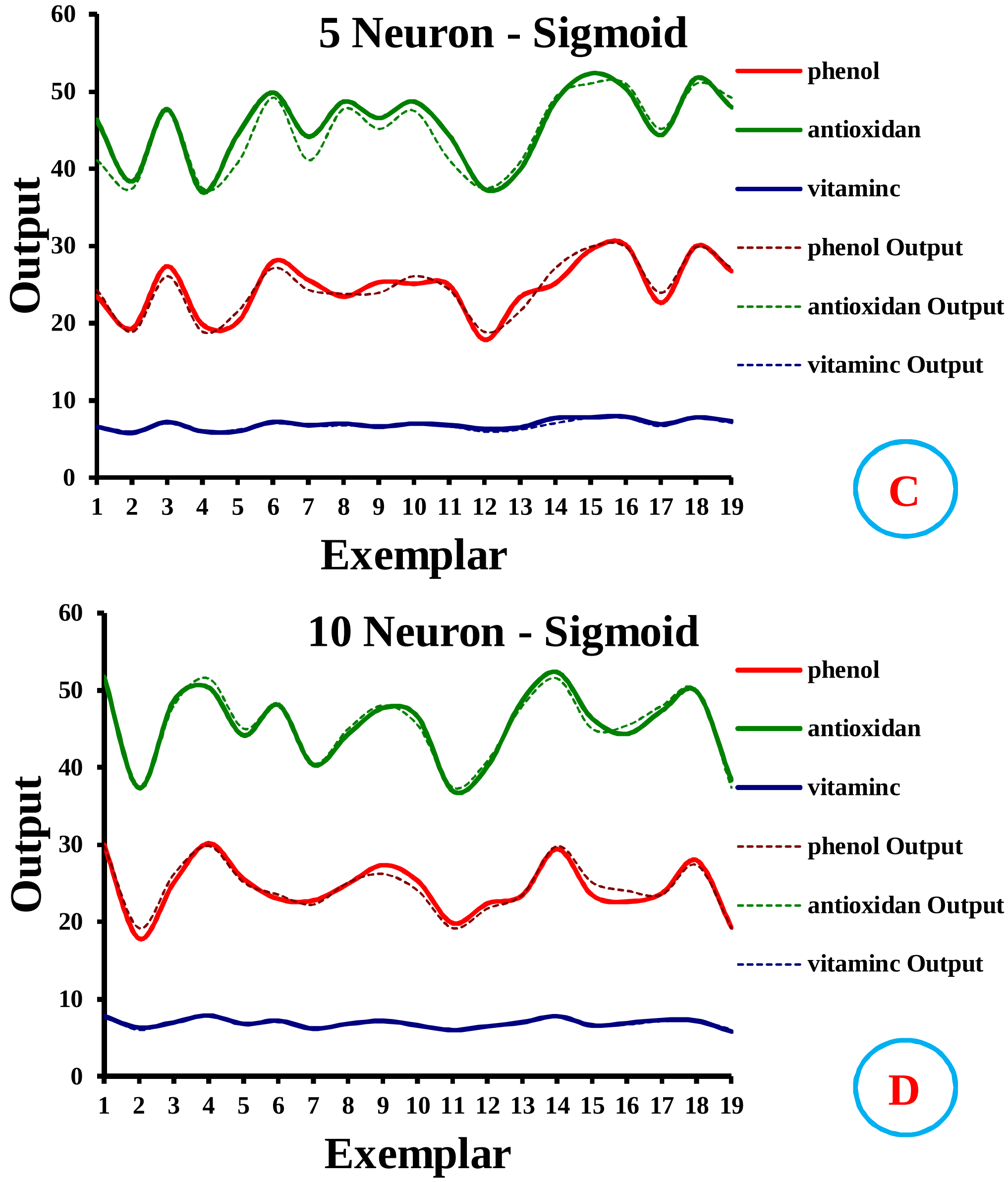


Fig. 3. Comparison of actual data with network output data

Sensitivity coefficient for quasi-static (thin edge)

The results of the sensitivity analysis for total phenol content are shown in Figure 4. Based on this figure, the highest sensitivity for training data was obtained for the loading in the hidden layers with 5 neurons and sigmoid activation and for storage was obtained in hidden layers with 5 neurons and hyperbolic tangent activation function (Figure 4). generally, in the case of total phenol content, it was loading sensitivity analysis more than storage sensitivity analysis, The reason for this can be justified by the fact that by creating stress (loading) in pears and causing internal damage to the fruit, some of the enzymes are released to repair the damaged tissue and reduce the activity of the fruit, which causes the decrease. As shown in figure 4, sensitivity analysis for test and cross validation data, According to figure highest sensitivity for test and cross validation data were obtained for loading in the hidden layers with 10 neurons by hyperbolic tangent activation (Test) and 5 neurons in sigmoid activation (Cross validation) for storage was obtained in hidden layers with 5 neurons and sigmoid activation (Figure 4). .Also, highest sensitivity for test and cross validation data were obtained for the storage in the hidden layers with 10 neurons (Test) and 5 neurons (Cross validation) in hyperbolic tangent activation for storage was obtained in hidden layers with 5 neurons and sigmoid activation (Figure4-B).

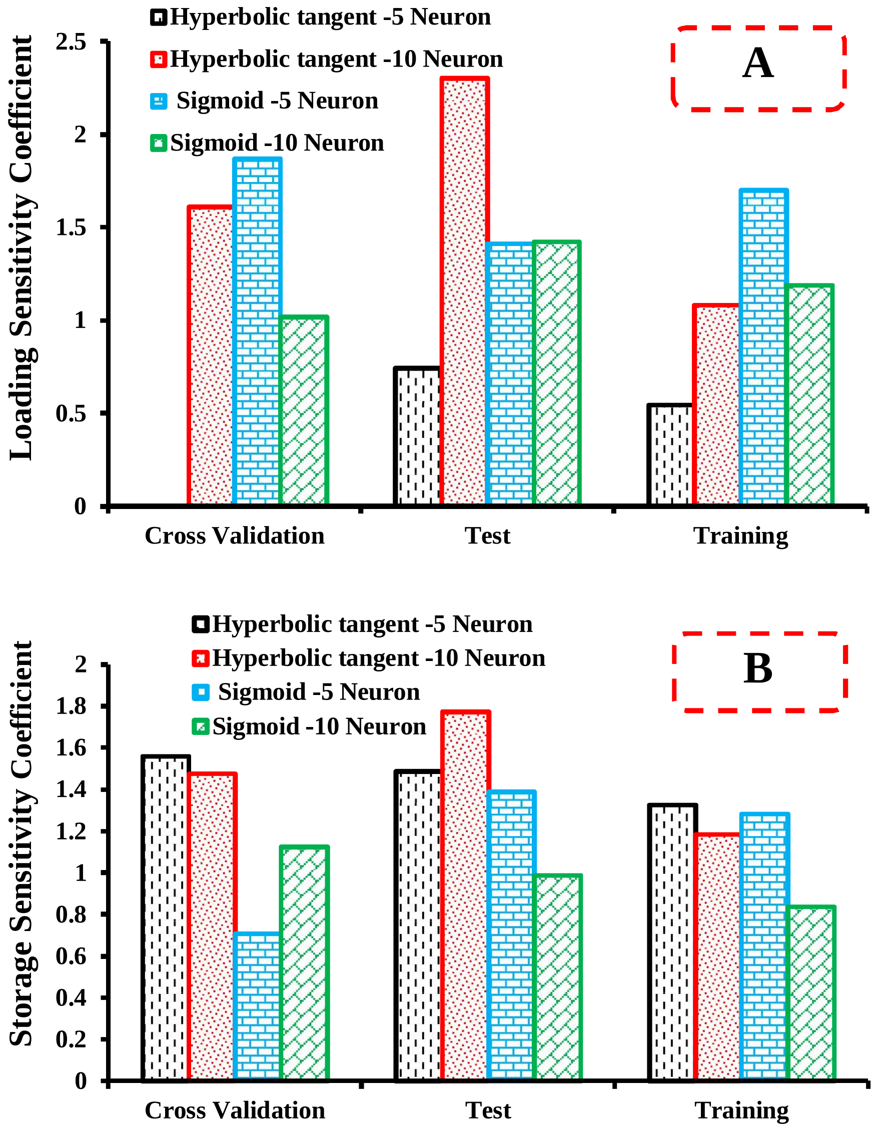


Fig. 4. Sensitivity coefficient for Total Phenol Content for A: Loading B: Storage time

The results of the sensitivity analysis for Antioxidant are shown in Figure 5. Based on this figure, the highest sensitivity for training data was obtained for the loading in the hidden layers with 5 neurons and sigmoid activation and for storage was obtained in hidden layers with 10 neurons and hyperbolic tangent activation (Figure 5).As shown in figure 5 the sensitivity analysis for test and cross calidation data, the highest sensitivity for test and cross validation data were obtained for loading in the hidden layers with 10 neurons by hyperbolic tangent activation (Test) and 5 neurons in sigmoid activation (Cross validation) (Figure 5). also, highest sensitivity for test and cross validation data were obtained for the storage in the hidden layers with 5 neurons in sigmoid activation (Test) and 5 neurons by hyperbolic tangent activation (Cross validation) (Figure5-B)

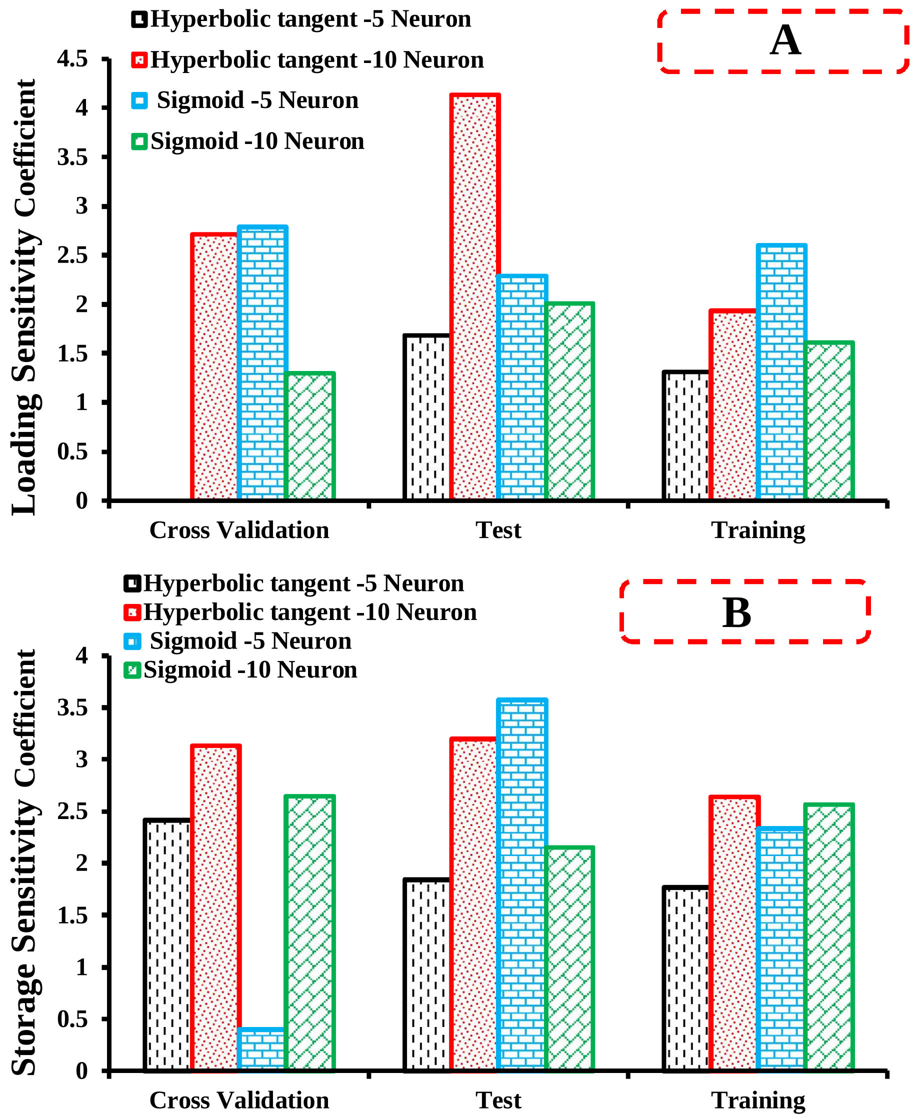


Fig. 5. Sensitivity coefficient for Antioxidant for A: Loading B: Storage time

The results of the sensitivity analysis for vitamin C are shown in Figure 6. Based on this figure, the highest sensitivity for training data was obtained for the loading in the hidden layers with 5 neurons and sigmoid activation and for storage was obtained in hidden layers with 10 neurons and hyperbolic tangent activation (Figure 6). As shown in figure 6, sensitivity analysis for test and cross Validation data, According to figure the highest sensitivity for test and cross validation data were obtained for loading in the hidden layers with 10 neurons by hyperbolic tangent activation (Test) and 5 neurons in sigmoid activation (Cross validation)(Figure 6). Also, highest sensitivity for test and cross validation data were obtained for the storage in the hidden layers with 10 neurons in hyperbolic tangent activation (Test) and 10 neurons by hyperbolic tangent activation (Cross validation) (Figure 6-B).

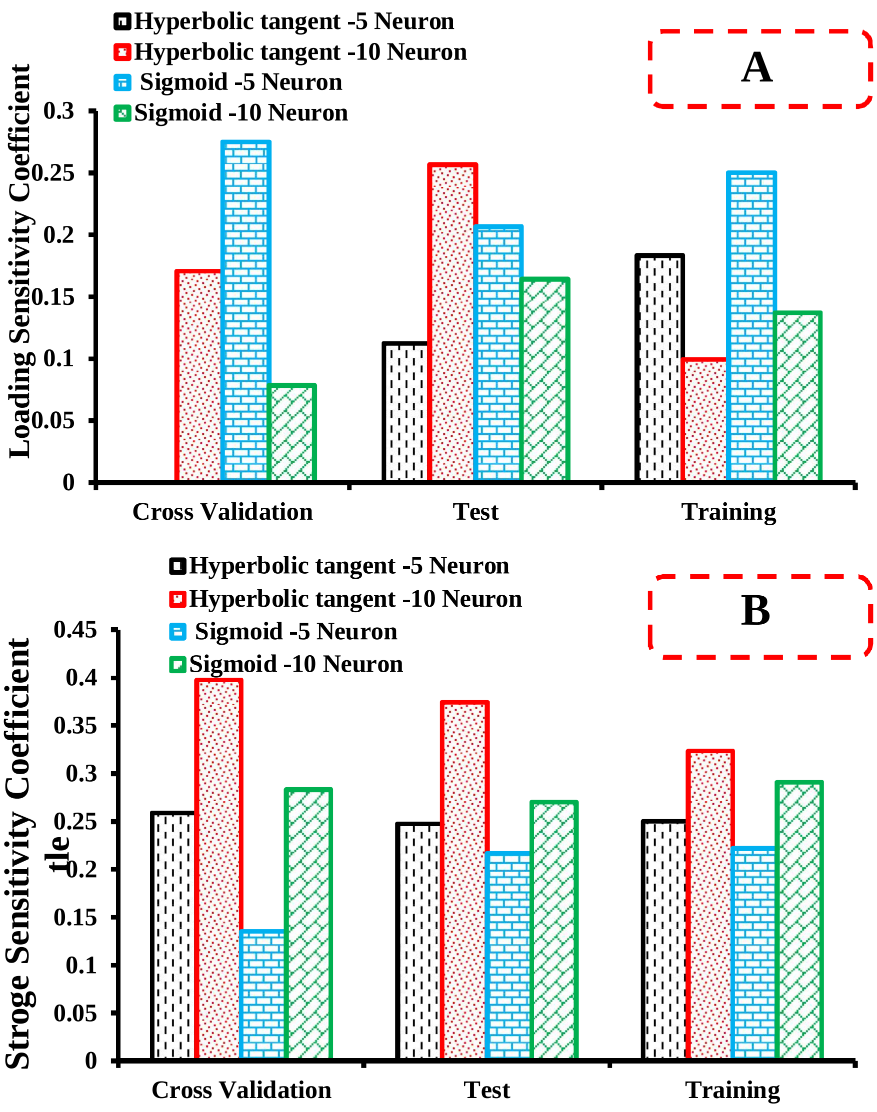


Fig. 6. Sensitivity coefficient for Vitamin-C for A: Loading B: Storage time

The quasi-static (Wide edge)

The results showed that neural network has 10 neurons in the hidden layer and Sigmoid activation function for Total Phenol Content (R^2= 0.9539), Antioxidant (R^2= 0.9839) and 5 neurons in the hidden layer and hyperbolic tangent activation function vitamin-C (R^2= 0.9758) can predict total phenol content, antioxidant and vitamin-C in different loading and storage time (table 5). In addition, the neural network with 10 neurons in the hidden layer and sigmoid activation have the lowest RMSE and MAE for total phenol content (RMSE= 0.713, MAE= 0.608) and antioxidant (RMSE= 1.475, MAE= 1.216) used. For vitamin-C (RMSE= 0.110, MAE= 0.086) the lowest RMSE and MAE value was obtained by the hidden layer was with 5 neurons and hyperbolic tangent activation. Guiné et al. (2014), using artificial neural network, modeled the antioxidant activity and phenolic compounds of bananas and neural network experiments, and showed that antioxidant activity and phenolic compounds could be predicted accurately from the input variables (Guiné et al., 2015)

Table 5- Error values for the quasi-static (Wide edge) in predicting experimental data using optimal artificial neural network

	Activation function	Neuron number	MSE		RMSE		MAE		R^2	
			Training	Test	Training	Test	Training	Test	Training	Test
Total Phenol Content	hyperbolic tangent	5	0.6723	1.0166	0.820	1.008	0.7079	0.6759	0.9819	0.9125
		10	1.3521	3.7249	1.163	1.930	1.0071	1.7355	0.9677	0.8349
	Sigmoid	5	0.98172	1.32438	0.991	1.151	0.82638	1.08686	0.98331	0.96781
		10	0.50768	0.8524	0.713	0.923	0.60858	0.7414	0.98650	0.9845
Antioxidant	hyperbolic tangent	5	2.8978	5.6542	1.702	2.378	1.4681	2.1755	0.9641	0.9313
		10	2.7867	3.9211	1.669	1.980	1.3370	1.5821	0.9534	0.9331
	Sigmoid	5	5.63087	1.37952	2.373	1.175	1.90505	0.97900	0.92684	0.93299
		10	2.17461	4.4689	1.475	2.114	1.21664	1.8540	0.96493	0.9539
Vitamin-C	hyperbolic tangent	5	0.0121	0.0664	0.110	0.258	0.0861	0.2377	0.9814	0.6919
		10	0.0230	0.0358	0.152	0.189	0.1234	0.1456	0.9677	0.9165
	Sigmoid	5	0.02006	0.09722	0.142	0.312	0.12184	0.26934	0.97009	0.35506
		10	0.01434	0.0550	0.120	0.235	0.10509	0.2010	0.97565	0.9391

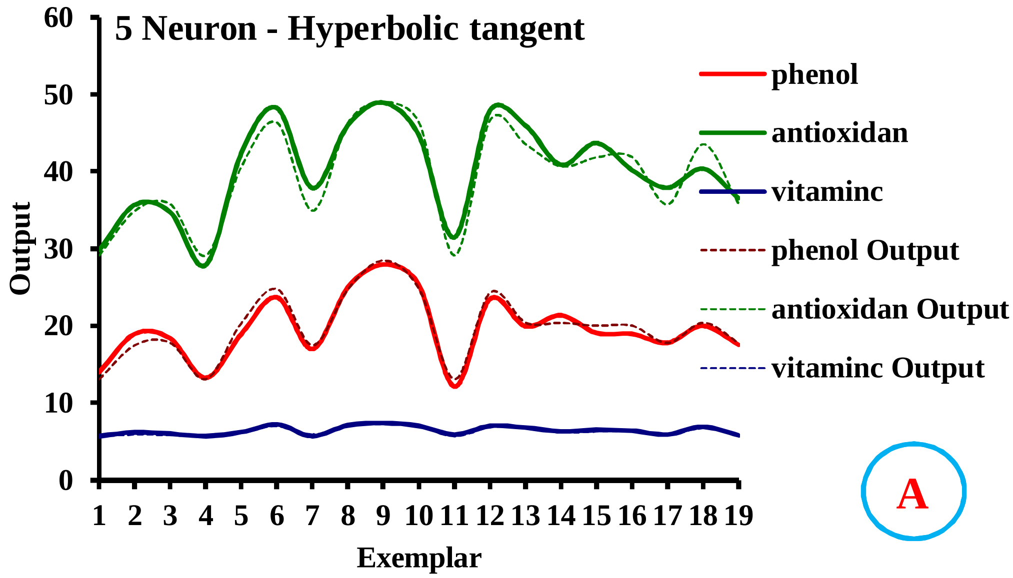
Table 6 also shows the best network between input data and data simulated by the network for each of the neurons in the hidden layer. The lower value of Epoch indicates that the number of neurons in the layer has been able to have learned from the neural network compared to an other number of neurons.

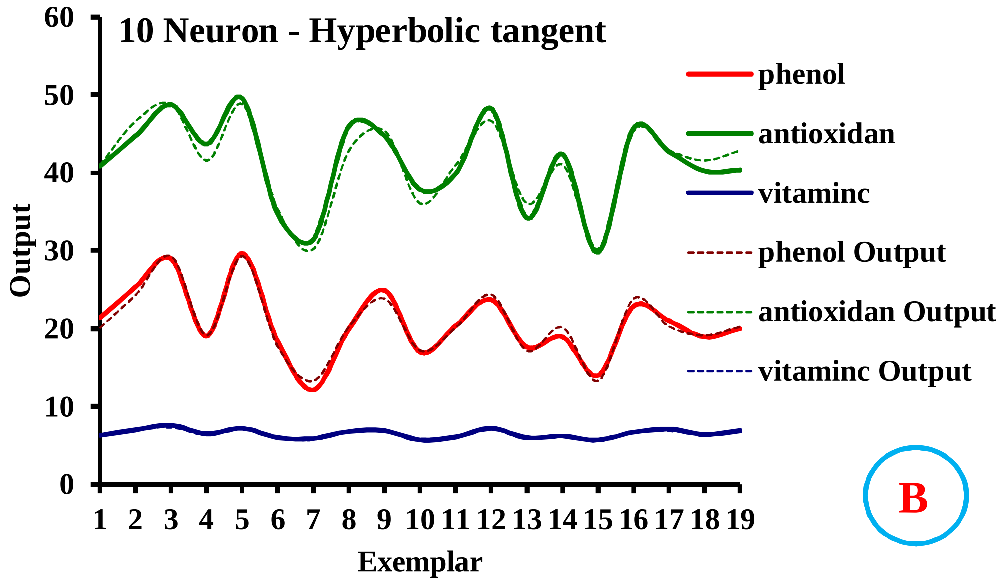
As shown in table 6, the best network for total phenol content at training (Run = 1, Epoch = 27) in the 10-neuron state in the hidden layer and hyperbolic tangent activation reaches to constant value after about 27 Epoch of error, and the best network for antioxidant training (Run = 1, Epoch = 27) in 5-neuron state in the hidden layer and sigmoid tangent activation. For vitamin-C of training value (Run = 1, Epoch = 42), it was found in 10-neuron state in the hidden layer and hyperbolic tangent and sigmoid activation.

Table 6- Some of the best MLP neural network topologies to predict training values

	Activation function	Neuron number	Run		Epoch	
			Training	Cross Validation	Training	Cross Validation
Total Phenol Content	hyperbolic tangent	5	2	2	603	21
		10	1	5	27	9
	Sigmoid	5	1	4	92	15
		10	1	1	49	14
Antioxidant	hyperbolic tangent	5	1	1	107	71
		10	1	1	33	13
	Sigmoid	5	1	1	27	11
		10	1	4	28	27
Vitamin-C	hyperbolic tangent	5	1	2	362	22
		10	1	1	42	7
	Sigmoid	5	1	2	50	40
		10	1	5	42	23

Also, figure (7) illustrates the output amounts of between the real and predicted data. It can be observed based on the figure that the neural network has been well capable of predicting and comparing the given numbers and it can be stated considering the closeness and similarity of the numbers outputted from the ANN to the real data that the neural network possesses an appropriate competency for data prediction. Moreover, considering the R^2 rates, the network with sigmoid activation function featuring 10 neurons in the hidden layer (figure 7-D) presents the best overlap with the real data.


5 Neuron - Hyperbolic tangent
Output
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Exemplar
phenol
antioxidan
vitaminc
phenol Output
antioxidan Output
vitaminc Output
A


10 Neuron - Hyperbolic tangent
Output
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Exemplar
phenol
antioxidan
vitaminc
phenol Output
antioxidan Output
vitaminc Output
B

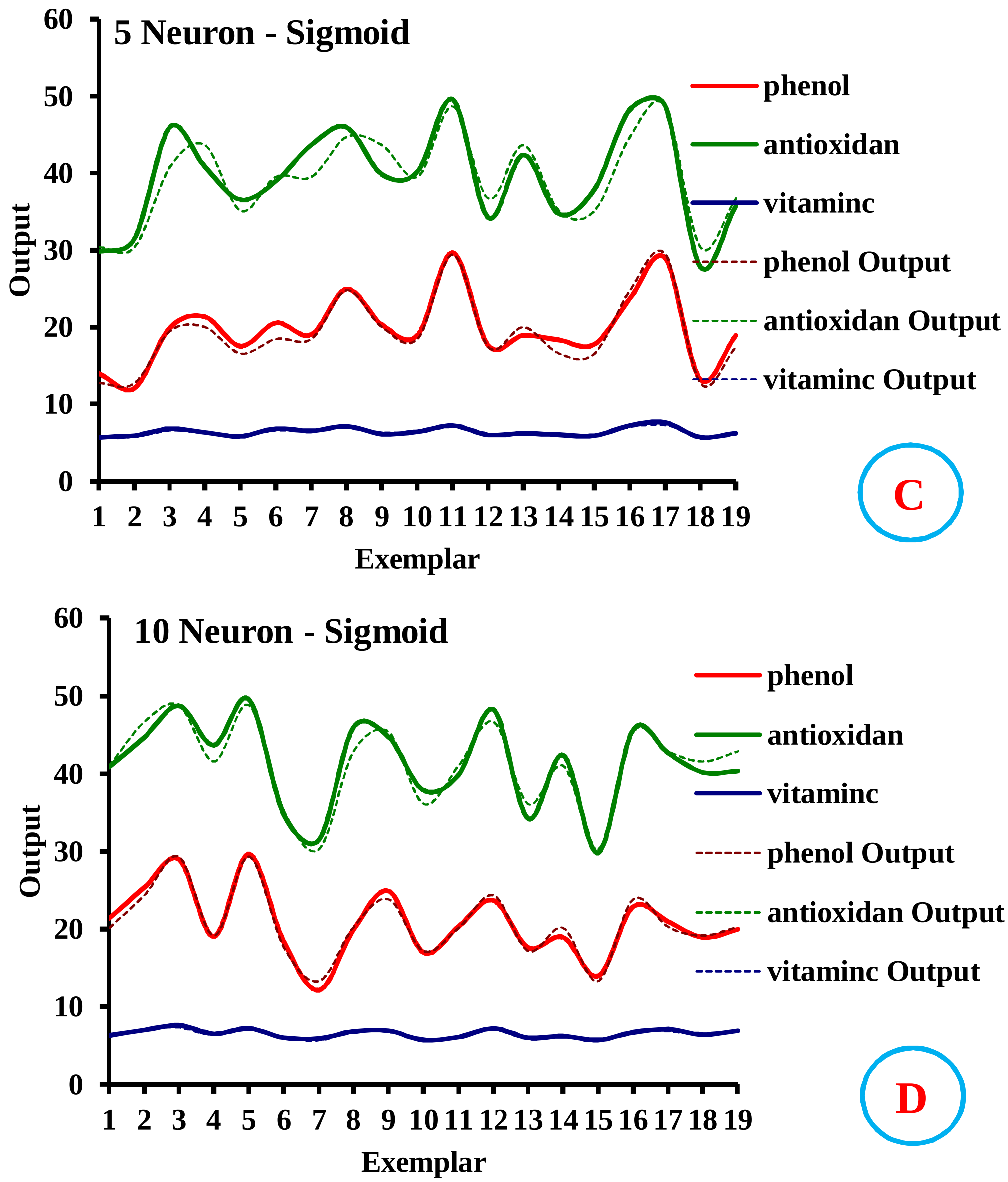


Fig. 7. Compare actual data with network output data

Sensitivity coefficient for quasi-static (wide edge)

The results of the sensitivity analysis for total phenol content are shown in Figure 8. Based on this figure, the highest sensitivity for training data was obtained for the loading and storage in the hidden layers with 5 neurons and hyperbolic tangent activation (Figure 8-A). As shown in figure 8 sensitivity analysis for test and Cross Validation data, According to figure highest sensitivity for test and cross validation data were obtained for loading and storage in the hidden layers with 5 neurons by sigmoid activation for test and Cross validation (Figure 8- A, B).

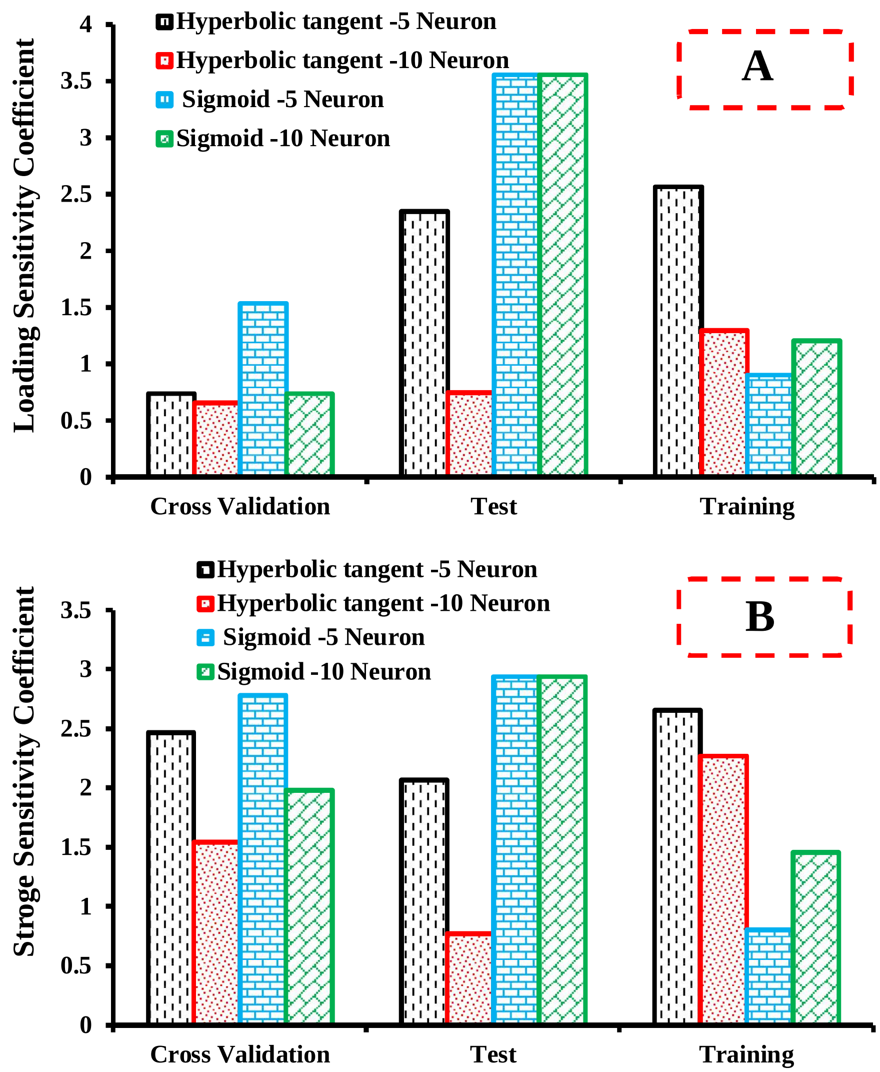


Fig. 8. Sensitivity coefficient for Total Phenol Content for A: Loading B: Storage time

The results of the sensitivity analysis for Antioxidant are shown in Figure 9. Based on this figure, the highest sensitivity for training data was obtained for the loading and storage in the hidden layers with 5 neurons and hyperbolic tangent activation (Figure 9- A). As shown in figure 9, sensitivity analysis for test and Cross validation data , According to figure the highest sensitivity for test and cross validation data were obtained for loading and storage in the hidden layers with 5 neurons by hyperbolic tangent activation (Test) and 10 neurons in sigmoid activation (Cross validation) (Figure 9- A, B).

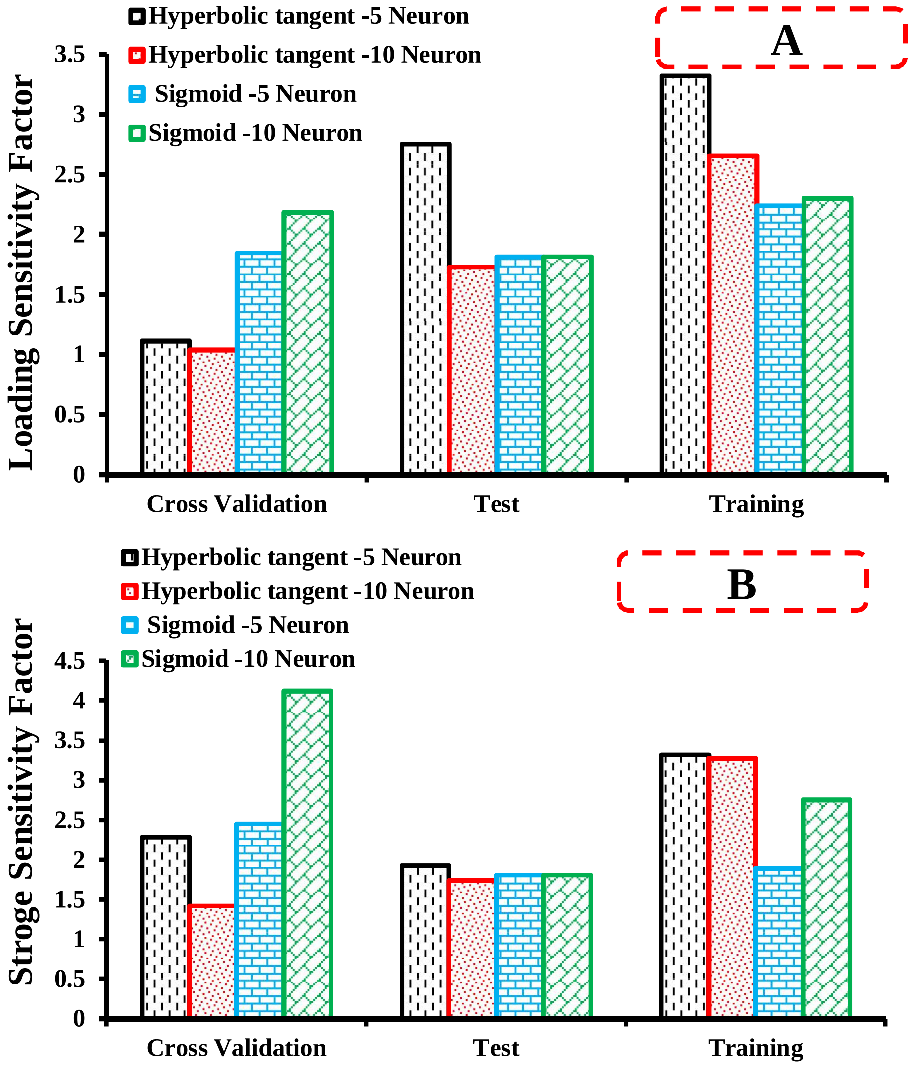


Fig. 9. Sensitivity coefficient for Antioxidant for A: Loading B: Storage time

The results of the sensitivity analysis for vitamin-C are shown in Figure 10. Based on this figure, the highest sensitivity for training data was obtained for the loading and storage in the hidden layers with 5 neurons and hyperbolic tangent activation (Figure 10-A). As shown in figure 10, sensitivity analysis for test and Cross validation data, According to figure the highest sensitivity for test and cross validation data was obtained for loading in the hidden layers with 5 neurons by hyperbolic tangent activation for Test and Cross validation (Figure 10-A, B) and For storage in the hidden layers with 5 neurons by hyperbolic tangent activation (Test) and 10 neurons in sigmoid activation (Cross validation)

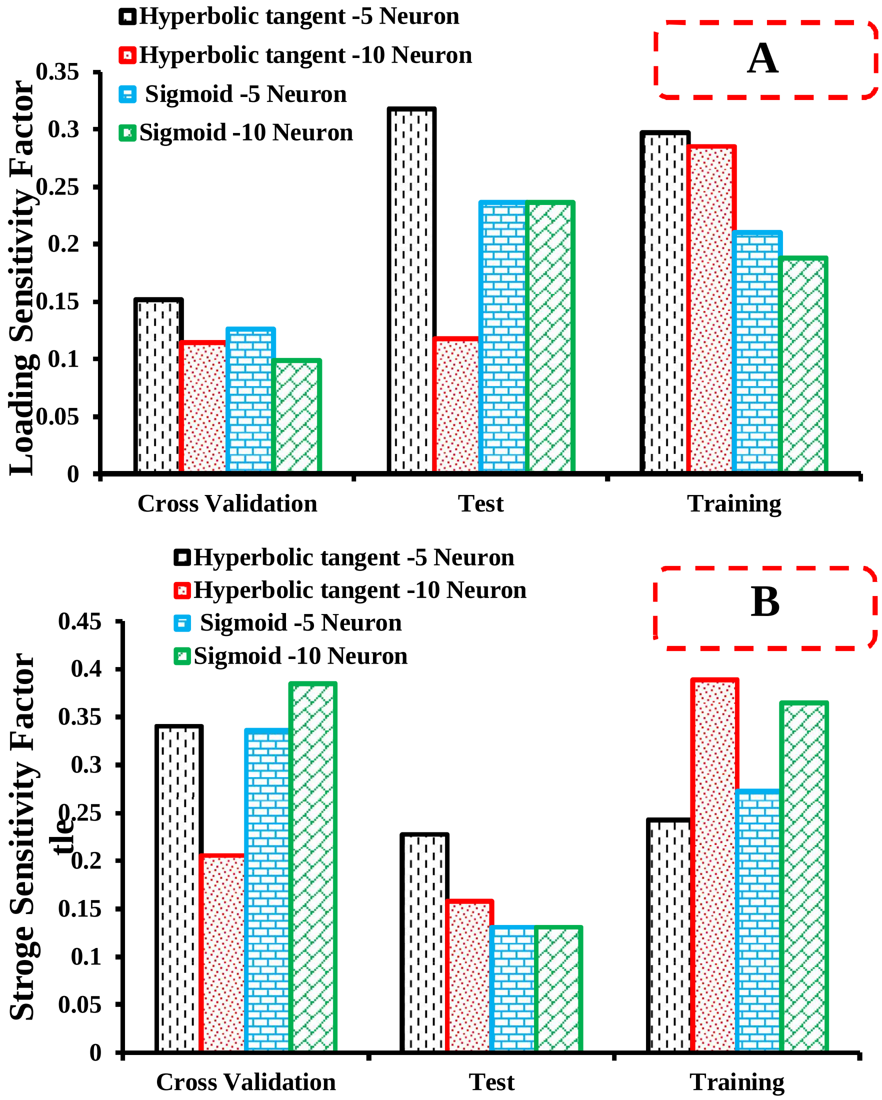


Fig. 10. Sensitivity coefficient for Vitamin-C for A: Loading B: Storage time

Conclusion

According to the values obtained for the determination coefficient (R^2), ANN was able to estimate the wide-edge loading determination coefficient comparing to the thin-edge loading determination coefficient and this is indicative of the idea that the ANN offers better abilities for the higher loading forces. The amount R_{test} for phenolic, antioxidant and vitamin C content in wide loading showed that the best values were in 10 neuron with sigmoid activation function and the amounts R_{test} were 0.9845, 0.9539 and 0.9391, respectively also in addition, in thin loading the highest R_{test} showed for phenol content in 5 neuron and hyperbolic tangent (0.9779) and for antioxidant and vitamin C showed in 10 neuron and hyperbolic tangent (0.9697 and 0.9691 respectively).

ANN has been able to estimate lower RMSE and MAE for wide-edge loading in contrast to thin-edge loading and this is suggestive of the idea that the ANN better fits higher loading forces' estimation.

As for the wide-edge loading force, R^2 values obtained for phenol, antioxidant and vitamin C contents were above 0.90 indicating the acceptability of the network.

According to the results obtained for wide-edge and thin-edge loading, the network with 10 neurons in the hidden layer and a sigmoid activation function can be accompanied with the best performance.

According to the simulation figures obtained by the network, the real and simulated data appropriately overlap.

The sensitivity coefficient obtained in training for wide-edge loading forces and storage periods in 5 and 10-neuron states of the hidden layer featuring a hyperbolic tangent activation function and 10-neuron state of the hidden layer with sigmoid activation function was higher than the one which was calculated for thin-edge loading.

As for the wide-edge loading, the highest sensitivity coefficient was obtained using a network with 5 neurons in the hidden layer and a hyperbolic tangent activation function in terms of total phenol, antioxidant and vitamin C contents. Moreover, the highest total phenol and antioxidant contents have also been found for the same number of neurons and activation function in terms of the storage period. As for the vitamin C content, the network with 10 neurons and hyperbolic tangent activation function has given the highest sensitivity coefficient.

In regard of the thin-edge loading, the highest sensitivity coefficient in terms of total phenol, antioxidant and vitamin C contents was obtained in the network with 5 neurons in the hidden layer and sigmoid activation function. Also, the highest vitamin C and antioxidant content in terms of the storage period were obtained in a network with 10 neurons in the hidden layer and hyperbolic tangent activation function. And, in terms of the total phenol content, the network with 5 neurons and the hyperbolic tangent activation function has had the highest sensitivity coefficient.

Reference

Azadbakht, M., Aghili, H., Ziaratban, A., Torshizi, M.V., 2017. Application of artificial neural network method to exergy and energy analyses of fluidized bed dryer for potato cubes. *Energy* 120, 947–958. https://doi.org/10.1016/j.energy.2016.12.006.

Azadbakht, M., Torshizi, M. V., & Mahmoodi, M. J.2019. The relation of pear volume and it's bruised volume by CT scan imaging. *Journal of Food Measurement and Characterization, 13*(2), 1089-1099.

Azadbakht, M., Torshizi, M.V., Ziaratban, A., 2016. Application of Artificial Neural Network (ANN) in predicting mechanical properties of canola stem under shear loading. *Agric. Eng. Int*. CIGR J. 18, 413–424.

B. Khoshnevisan, Sh. Rafiee, M. Omid, M.Y., 2013. Prediction of environmental indices of Iran wheat production using artificial neural networks. *Int. J. Energy Environ*. 4, 339–348.

Bai, J.-W., Xiao, H.-W., Ma, H.-L., Zhou, C.-S., 2018. Artificial neural network modeling of drying kinetics and color changes of ginkgo biloba seeds during microwave drying process. *J. Food Qual*. 2018.

Beale, R., Jackson, T., 1998. Neural Computing: An Introduction, London, UK, Institude of Physics Publishing, Bristol BSI 6BE. https://doi.org/008.3

Chasiotis, V.K., Tzempelikos, D.A., Filios, A.E., Moustris, K.P., 2019. Artificial neural network modelling of moisture content evolution for convective drying of cylindrical quince slices. Comput. Electron. Agric. 105074.

Galvis-Sánchez, A.C., Fonseca, S.C., Morais, A.M.M.B., Malcata, F.X., 2004. Sensorial and physicochemical quality responses of pears (cv Rocha) to long-term storage under controlled atmospheres. *J. Sci. Food Agric*. 84, 1646–1656. https://doi.org/10.1002/jsfa.1798

Guiné, R.P.F., Barroca, M.J., Gonçalves, F.J., Alves, M., Oliveira, S., Mendes, M., 2015. Artificial neural network modelling of the antioxidant activity and phenolic compounds of bananas submitted to different drying treatments. Food Chem. 168, 454–459. https://doi.org/10.1016/j.foodchem.2014.07.094

Gurrieri, S., Miceli, L., Lanza, C.M., Tomaselli, F., Bonomo, R.P., Rizzarelli, E., 2000. Chemical characterization of sicilian prickly pear (*Opuntia ficus indica*) and perspectives for the storage of its juice. *J. Agric. Food Chem.* 48, 5424–31. https://doi.org/10.1021/jf9907844

Jaramillo-Flores, M.E., González-Cruz, L., Cornejo-Mazón, M., Dorantes-álvarez, L., Gutiérrez-López, G.F., Hernández-Sánchez, H., 2003. Effect of Thermal Treatment on the Antioxidant Activity and Content of Carotenoids and Phenolic Compounds of Cactus Pear Cladodes (O*puntia ficus-indica*). *Food Sci. Technol. Int.* 9, 271–278. https://doi.org/10.1177/108201303036093

Jebri, M., Tarrazó, J., Bon, J., Desmorieux, H., Romdhane, M., 2018. Intensification of the convective drying process of Salvia officinalis: Modeling and optimization. *Food Sci. Technol. Int.* 24, 382–393.

Kazem, A., Hassan, K., Mohamad-Jafar, M., Mohsen, B., 2015. Postharvest physicochemical changes and properties of Asian (*Pyrus serotina Rehd* .) & European (*Pyrus communis* L .) pear cultivars Postharvest Fruit Physicochemical Changes and Properties of Asian. Hort. Environ. Biotechnol. 49(4), 244–252.

Li, W.L., Li, X.H., Fan, X., Tang, Y., Yun, J., 2012. Response of antioxidant activity and sensory quality in fresh-cut pear as affected by high O2active packaging in comparison with low O2 packaging. *Food Sci. Technol. Int.* 18, 197–205. https://doi.org/10.1177/1082013211415147

Lu, H., Zheng, H., Lou, H., Jiang, L., Chen, Y., Fang, S., 2010. Using neural networks to estimate the losses of ascorbic acid, total phenols, flavonoid, and antioxidant activity in asparagus during thermal treatments. *J. Agric. Food Chem.* 58, 2995–3001. https://doi.org/10.1021/jf903655a

Malakouti, M.J., Barzegar, M., Arzani, K., Khoshghalb, H., 2009. Polyphenoloxidase activity, polyphenol and ascorbic acid concentrations and internal browning in Asian pear (*Pyrus serotina Rehd.*) Fruit during storage in relation to time of harvest. *Eur. J. Hortic.* Sci. 74, 61–65.

Mazloumzadeh, S.., Alavi, S.., Nouri, M., 2008. Comparison of Artificial Neural and Wavelet Neural Networks for Prediction of Barley Breakage in Combine Harvester. *J. Agric*. 10, 181–195.

Menhaj, M., 2000. Foundation of Artifitioal Neural Networks. Amir Kabir univercity.

Nadian, M.H., Rafiee, S., Aghbashlo, M., Hosseinpour, S., Mohtasebi, S.S., 2015. Continuous real-time monitoring and neural network modeling of apple slices color changes during hot air drying. *Food Bioprod. Process.* 94, 263–274.

Salehi, F. 1, Gohari Ardabili, A., Nemati, A. 2, Latifi Darab, R., 2017. Modeling of strawberry drying process using infrared dryer by genetic algorithm–artificial neural network method. *J. Food Sci. Technol*. 14, 105–114.

Salehi, F., Razavi, S.M.A., 2012. Dynamic modeling of flux and total hydraulic resistance in nanofiltration treatment of regeneration waste brine using artificial neural networks. Desalin. Water Treat. 41, 95–104. https://doi.org/10.1080/19443994.2012.664683

Soleimanzadeh, B., Hemati, L., Yolmeh, M., Salehi, F., 2015. GA-ANN and ANFIS models and salmonella enteritidis inactivation by ultrasound. J. *Food Saf.* 35, 220–226. https://doi.org/10.1111/jfs.12174

Taheri-Garavand, A., Karimi, F., Karimi, M., Lotfi, V., Khoobbakht, G., 2018. Hybrid response surface methodology–artificial neural network optimization of drying process of banana slices in a forced convective dryer. *Food Sci. Technol. Int.* 24, 277–291. https://doi.org/10.1177/1082013217747712

Tavarini, S., Degl'Innocenti, E., Remorini, D., Massai, R., Guidi, L., 2008. Antioxidant capacity, ascorbic acid, total phenols and carotenoids changes during harvest and after storage of Hayward kiwifruit. *Food Chem.* 107, 282–288. https://doi.org/10.1016/j.foodchem.2007.08.015

Torkashvand, A.M., Ahmadi, A., Nikravesh, N.L., 2017. Prediction of kiwifruit firmness using fruit mineral nutrient concentration by artificial neural network (ANN) and multiple linear regressions

(MLR). *J. Integr. Agric.* 16, 1634–1644. https://doi.org/10.1016/S2095-3119(16)61546-0

Yurtlu, Y.B., Erdoğan, D., 2005. Effect of storage time on some mechanical properties and bruise susceptibility of pears and apples. Turkish J. Agric. For. 29, 469–482.

Zarifneshat, S., Rohani, A., Ghassemzadeh, H.R., Sadeghi, M., Ahmadi, E., Zarifneshat, M., 2012. Predictions of apple bruise volume using artificial neural network. *Comput. Electron. Agric.* 82, 75–86.

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جلد 16، شماره 3، مرداد - شهریور 1399، ص. 85-63

پیش‌بینی تغییرات خواص فیزیولوژی در گلابی‌های تحت بارگذاری خارجی با استفاده از شبکه عصبی مصنوعی: بخش 1: بارگذاری استاتیکی

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چکیده

در این مقاله به بررسی اثر نیروی بارگذاری و دوره انبارداری بر میزان محتویات درونی گلابی پرداخته شده است. در این آزمایش گلابی‌ها تحت بارگذاری شبه استاتیکی (لبه نازک-لبه پهن) و دوره‌های انبارداری مختلف (5، 10 و 15 روز) قرار گرفته است. پس از هر دوره انبارداری میزان محتوای فنول کل میوه، آنتی‌اکسیدان و ویتامین C میوه مورد بررسی قرار گرفت. در این پژوهش شبکه عصبی مصنوعی پرسپترون چندلایه (MLP) با یک لایه پنهان و دو نوع تابع فعال‌سازی (Hyperbolic tangent - sigmoid) و تعداد 5، 10 نرون در هر لایه برای نیروی بارگذاری و دوره انبارداری جهت پیشگویی میزان میزان محتوای فنول کل میوه ، آنتی‌اکسیدان و ویتامین C انتخاب گردید. با توجه به نتایج به‌دست آمده بیشترین مقدار R^2 برای بارگذاری لبه نازک و پهن در شبکه‌ای که دارای 10 نرون در لایه پنهان و تابع فعال‌سازی sigmoid برای محتوای فنول کل ($R^2_{Thin\ sdge}$=0.9539 - $R^2_{Wide\ edge}$ =0.9865) ، انتی‌اکسیدان ($R^2_{Thin\ sdge}$=0.9839 - $R^2_{Wide\ edge}$ =0.9649) و ویتامینC ($R^2_{Thin\ edge}$=0. 9758) بوده است و برای ویتامین C ($R^2_{Wide\ edge}$=0.9865) بارگذاری لبه پهن بیشترین مقدار R^2 در شبکه با 5 نرون در لایه پنهان و تابع فعال‌سازی Hyperbolic tangent بوده است. با توجه به نتایج به‌دست آمده شبکه عصبی با این دو نوع تابع فعال‌سازی توانایی مناسبی در همپوشانی و پیش‌بینی داده‌های شبیه‌سازی شده با داده‌های واقعی را داشته است .

واژه‌های کلیدی: محتویات درونی گلابی، بارگذاری، انبارداری، شبکه عصبی، تابع فعال‌سازی

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