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MICROSTRUCTURES AND ELEMENTAL DISTRIBUTION OF MAGNETIC FIELD PRE-TREATED FLUTED PUMPKIN LEAF

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There is a scarcity of studies on the use of magnetic field for food pretreatment, especially in relation to a knowledge on the pretreatment at the level of microstructures and elemental distribution of food. Therefore, the effect of magnetic field pretreatment on the microstructures and elemental distribution (Na, K, Ca, Mg and Fe) of fluted pumpkin leaf was studied. Three types of magnetic field (static, pulse and alternating) in combination with varying magnetic field strength (5–30 mT) and pretreatment time (5–25 min) were used as variable factors. Fresh (untreated) and blanched samples were used for experiment control. After the pretreatment, all samples were dried at 50 °C and analysed in terms of microstructure and elemental distribution using scanning electron machine. Results showed that fresh and blanched samples of fluted pumpkin leaf exhibited microstructural features that were clearly different from samples pretreated by magnetic field. Pretreated samples showed contents of: 1.3–4.35% sodium; 1.20–3.42% potassium; 1.19–6.10% calcium; 0–5.10% magnesium and 1.22–6.62% iron. Changes in microstructures of samples caused by magnetic field pretreatment led consequently to better retention/improvement in elemental distribution in contrast to blanched and fresh samples in majority of cases.

Keywords: non-thermal processing; vegetables; effect; electromagnetism; thermal processing

Fluted pumpkin leaf (*Telfairia occidentalis*) is a leafy vegetable that has high nutritional and medicinal values (Ndor et al., 2013). It is referred to as “ugu” among the Igbo ethnic group of Nigeria (Odewole et al., 2015) and the name has been popularly adopted for use across most parts of Nigeria. Fluted pumpkin leaf can improve haematological parameters, has anti-inflammatory and anticholesterolemic properties (Obeagu et al., 2014). The leaf has microstructures just like any other vegetables (Verboven et al., 2018b).

Food microstructure is the organization and interaction of food constituents resulting in a particular microscopically visible spatial partition of different material phases (Verboven et al., 2018a). Rejaul et al. (2018) defined the food microstructure as the arrangement of its architectural elements into organized structures either naturally or through processing. Food microstructure was also reported as the architectural view of food at submicroscopic levels; and it helps to better understand the internal behaviour of processed food, as well as when new products are to be developed and during quality control operations (Rejaul et al., 2018).

Foods nutrients are ingested in the form of microstructures that can be as small as nanometres and up to a few millimetres in size (Troncoso and Aguilera, 2009). Microstructural studies help in the establishment of the relationship that exists in composition, processing and final properties of many food products (Heertje, 1993).

Food pretreatment involves taking necessary steps in order to maintain the desired properties or nature of food for as long as possible and to ensure the consumption of food with high nutritional values (Rahman and Perera, 2007). Both processing and pretreatment affect the food microstructures either by destroying the original food structures or creating new ones. Pretreatment as one of the unit operations in food processing has the tendency of modifying the microstructures and elemental composition of food. With the use of SEM (scanning electron machine), Vodal et al. (2012) reported that blanching pretreatment did not affect the pore size distribution of freeze-dried winter carrot. Dhawi et al. (2009) pretreated the seedlings of date palm with static magnetic field (SMF) of strength from 10 mT to 100 mT for 30–360 min. Elemental analysis of the date palm leaf with inductive couple plasma (ICP) spectroscopy showed increase in the concentrations of Ca, Mg, Mn, Fe, Na, K, and Zn; however, phosphorus (P) concentration dropped with increase in SMF strengths and exposure duration. Antonio et al. (2008) used SEM to confirm the formation of pores within the microstructure (tissue) of sweet potato treated with osmotic dehydration. Starodubtseva et al. (2018) pretreated winter wheat seeds with pulsed electric field of up to 2,500 V·m⁻¹ field intensity, 50 µs pulse duration and 600 Hz pulse frequency; finally, it was observed that the seed moisture content increased from 10% to 13.5% with corresponding mass

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increase of approx. 23.8%. Moreover, Otero et al. (2000) used histological technique to evaluate modifications in the microstructures of peach and mango. The results showed that both products maintained their original tissue structures to a great extent. Askari et al. (2004) investigated the effect of hot air drying and microwave drying methods on microstructural changes of apple slices as further processing steps to osmotic pretreatment in sucrose solution (60% w/w). The microstructure revealed resistance of microstructures to damage and increase in porosity of the products. Food pretreatment/processing methods can be broadly classified as conventional and non-conventional (Neetoo and Chen, 2014); both methods have thermal and non-thermal examples. Conventional methods include those that are commonly used, such as: blanching, salting, thermal pasteurization and sterilization. Non-conventional methods are scarcely used and referred to as novel or emerging methods in food processing. Some typical examples include: high hydrostatic pressure, pulsed electric field, microwave heating, ohmic heating, sous vide method, irradiation, pulsed light (Neetoo and Chen, 2014) and magnetic field (Barbosa-Canovas et al., 2005). Emerging non-thermal technologies focus on the production of higher quality food in contrast to heat-treatment methods as well as on decrease in the processing costs and value addition to the product (Barbosa-Canovas et al., 2005).

A magnetic field is defined as a region of space in which a magnetic body is capable of inducing the surrounding bodies (Barbosa-Canovas et al., 2005) either with permanent magnet or temporary magnet (electromagnet). Magnetic fields are classified as of low or high intensity according to their relative strength; as homogeneous or non-homogeneous according to the variation of intensity over space; as static or pulsed according to time interval (Kovacs et al., 1997). Use of magnetic fields as a non-thermal food processing method was first proposed in 1985 (Barbosa-Canovas et al., 2005). Electromagnetic technologies in food processing have attracted increased industrial interest, because they represent a potential replacement of certain thermal food processing methods and can enhance other beneficial factors for food processing (Rahman and Perera, 2007). It was reported in ICNRIP (2009) that all the studies conducted so far did not give convincing evidence of the harmful effects of magnetic fields on living things. However, these guidelines suggest the acceptable exposure limit for different parts of human body: 2–8 T for head, torso and limbs, and 400 mT for any other part of the body.

Basic theory governing the use of magnetic field for food pretreatment could be adapted or assumed from the submission of Dhawi et al. (2009) stating that living cells have charges exerted by ions or free radicals which act as endogenous (internal) magnets; these can be affected by exogenous magnet or an external magnetic field from either permanent magnet or electromagnet. This interaction would cause the naturally unpaired electrons (or scattered ions) present in the internal parts of food materials to be rearranged in uniform manner. Similarly, Ordonez and Berrio (2011) came to conclusion that biological membranes exhibited a strong orientation in magnetic field (MF) and the ions in them were responsible for the transmission of the effects of the MF treatments to various parts of the materials.

Vegetables are living things, and hence contain cells; when harvested, their cells do not die immediately. These cells (which contain ions in them) would interact with an external magnetic field, resulting in the assumed modification of the microstructures leading to different responses of elements (minerals) present in the food product after exposure for a certain period of time. Several researchers (Hayder et al., 2015; Lipiec et al., 2004; Ordonez and Berrio 2011; Jia et al., 2015; Kyle, 2015; Ibara et al., 2015) have used magnetic field to carry out food processing. Few research works on the use of magnetic field to pretreat/process food are available and there has seemed to be a scarcity of information on the microstructures of food processed with magnetic field, and relationship between food microstructures and their elemental distribution. Therefore, the objective of this study was to investigate the effect of three types of magnetic fields (static magnetic field (SMF); pulse magnetic field (PMF); and alternating magnetic field (AMF)), varying magnetic field strength (5–30 mT) and various pretreatment times (5–25 min) on the microstructures and elemental distribution of fluted pumpkin leaf. The outcome of this research is a relevant reference point for future similar studies.

Material and methods

The following materials and equipment were used: a magnetic field (MF) pretreatment device; electronic weighing balance (OHAUS, Model 201, China); laboratory oven (Model SM9053, England); desiccator; scanning electron machine (JEOL, JSM-7600F, Japan); and fresh samples of fluted pumpkin leaf (FPL).

Fresh samples of FPL were procured, sorted, washed, cut, measured with the electronic weighing balance and pretreated using the MF device. Three types of magnetic fields (SMF, PMF and AMF) were used in combination with magnetic field strengths within the range (5–30 mT) and at pretreatment time (5–25 min). Fresh and water blanched samples of FPL were used for control purposes. After the pretreatment operation, all samples were immediately dried at 50 °C inside the laboratory oven for approx. 1 hour to an average moisture content of approx. 10% (db) and were taken for microstructural and elemental distribution analyses with the use of SEM. The experiment was conducted at the Food Engineering Laboratory of University of Ilorin, Nigeria in December 2018. The average laboratory temperature and average laboratory relative humidity during the drying process were 31 °C and 61%, respectively.

Results and discussion

Microstructures of MF pretreated fluted pumpkin leaf

Figs. 1(a–h) show the microstructures of FPL samples pretreated with SMF, PMF and AMF, as well as fresh and blanched samples. As it can be observed from the figures, fresh and blanched FPL samples (Figs. 1 h and g) exhibited microstructural features that are clearly different from MF pretreated samples (Figs. 1 a–f). This is an early indication

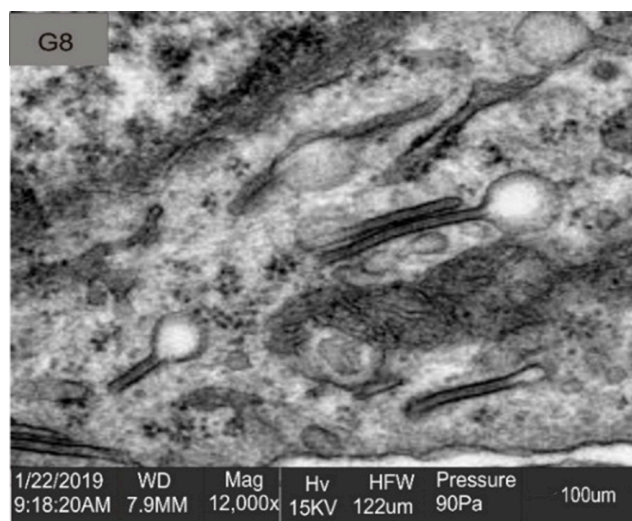


Fig. 1a (i) Microstructure of FPL at SMF (8 mT and 5 min)

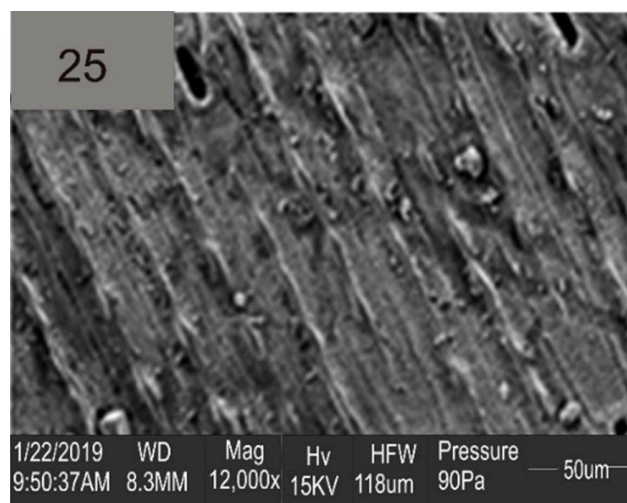


Fig. 1a (ii) Microstructure of FPL at PMF (8 mT and 5 min)

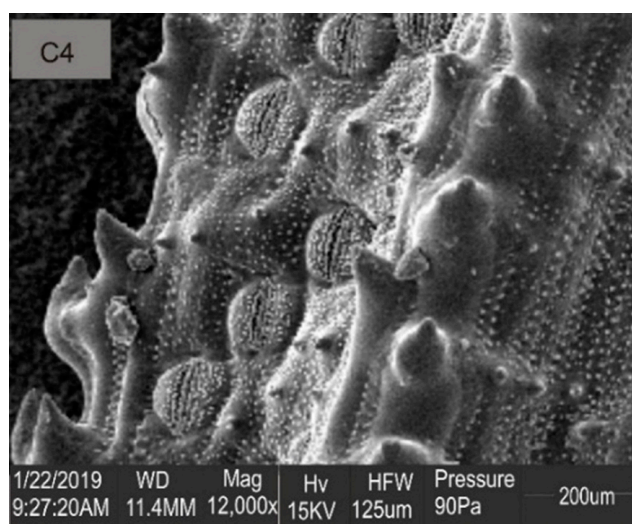


Fig. 1b (i) Microstructure of FPL at SMF (19 mT and 15 min)

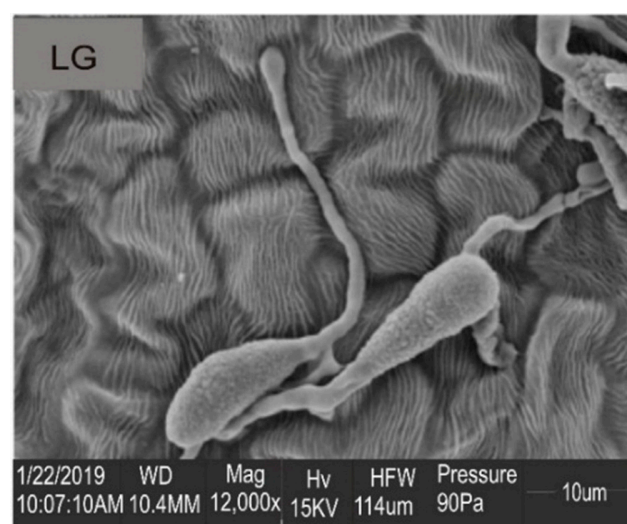


Fig. 1b (ii) Microstructure of FPL at PMF (19 mT and 15 min)

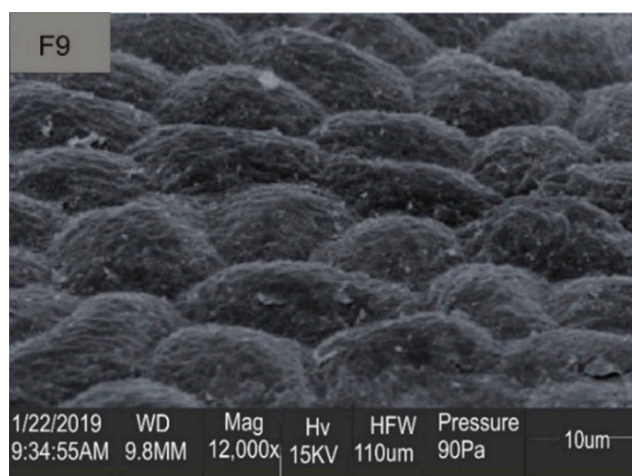


Fig. 1c (i) Microstructure of FPL at SMF (30 mT and 25 min)

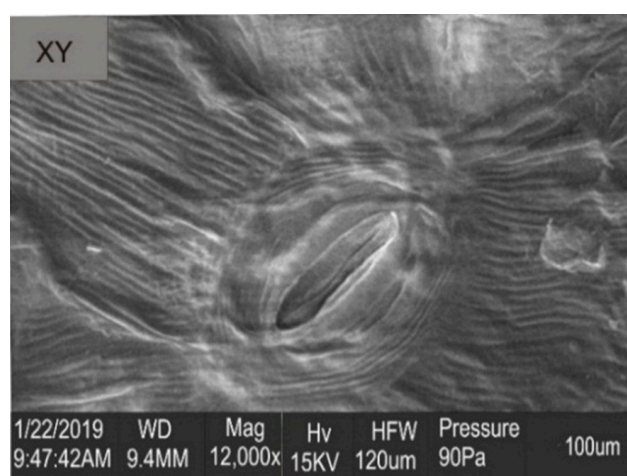


Fig. 1c (ii) Microstructure of FPL at PMF (30 mT and 25 min)

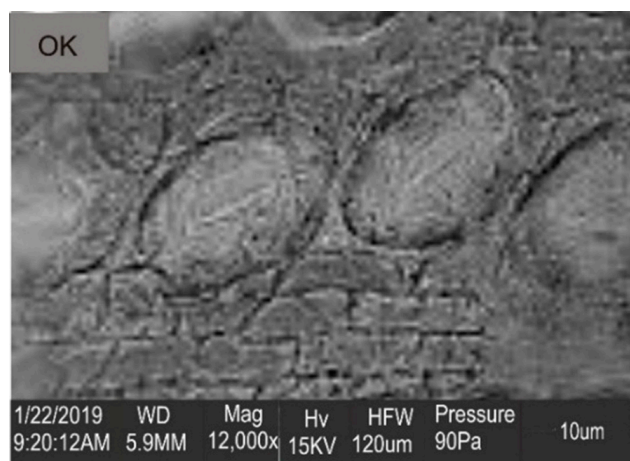


Fig. 1d Microstructure of FPL at AMF (5 mT and 5 min)

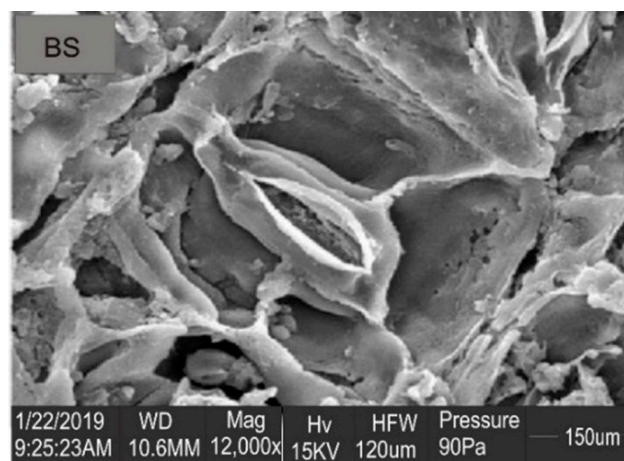


Fig. 1e Microstructure of FPL at AMF (9.5 mT and 15 min)

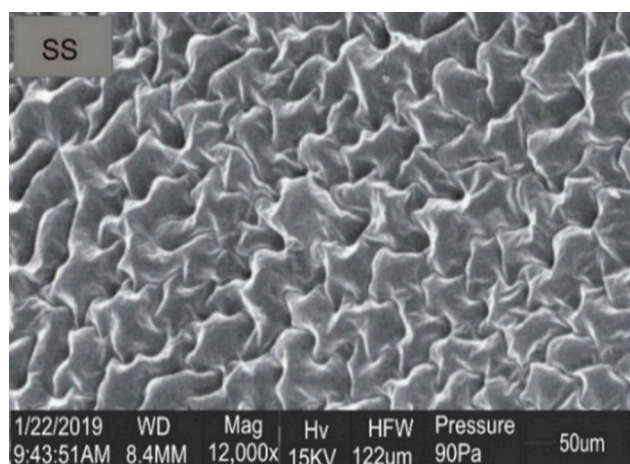


Fig. 1f Microstructure of FPL at AMF (14 mT and 25 min)

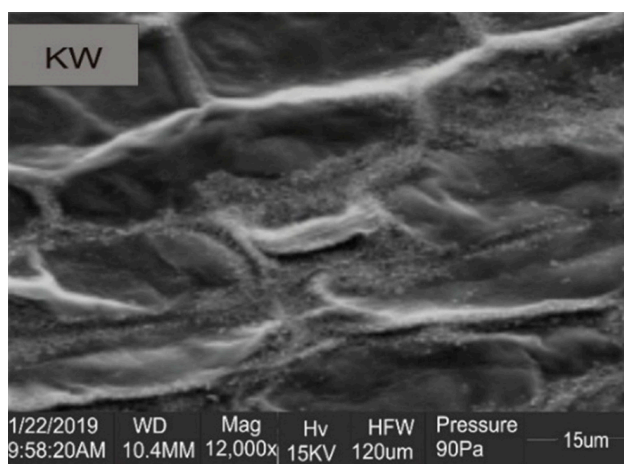


Fig. 1g Microstructure of FPL for blanched

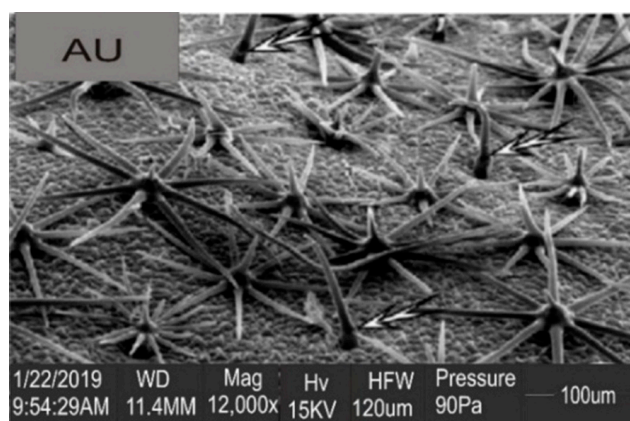


Fig. 1h Microstructure of FPL for fresh

that the three types of magnetic field used for pretreating the products caused different effects on their microstructures. These observations might be due to the fact that SMF, PMF and AMF have different wave patterns and characteristics. SMF is generated with full rectification of alternating current (AC) and its wave pattern is an approximated unidirectional straight line along the positive x-axis of voltage (V) versus time (t) graph. PMF is achieved with partial rectification of

AC; it is also unidirectional along the positive x-axis with formation of distinct ripples. On the other hand, the AMF is generated when the raw alternating current is flowing; it has the frequency with sinusoidal wave pattern (Bird, 2010); hence, it is non-unidirectional, that is, its wave moves across both the positive and negative horizontal axes of the voltage-time graph.

The microstructures obtained for the MF pretreated FPL samples could be described as puffy: SMF (30 mT and 25 min) – Fig. 1c (i); partially serrated: SMF (19 mT and 15 min) – Fig. 1b (i); with wood bark pattern: PMF – (8 mT and 5 min) – Fig. 1a (ii); with collapsed interlocks: (14 mT and 25 min) – Fig. 1f; with burst puff: AMF (9.5 mT and 15 min) – Fig. 1e; and other patterns that cannot be easily described with high level of certainty. The fresh sample (Fig. 1h) showed multiple clusters of visible spikes, and this pattern did not occur in any of the SMF, PMF, AMF pretreatment combinations, nor the blanched samples (Fig. 1g). Antonio et al. (2008) used SEM to confirm the formation of pores within the microstructure (tissue) of sweet potato; this was achieved when a study on osmotic dehydration and high temperature short time (HTST) pretreatment of sweet potato together with convective drying was conducted. Furthermore, Vodal et al. (2012) reported that blanching process was unable to affect the pore size

Table 1 Elemental distribution of MF pretreated, blanched and fresh FPL samples

Magnetic field types	Na (%)	K (%)	Ca (%)	Mg (%)	Fe (%)
SMF (8 mT and 5 min)	1.30	2.70	5.20	3.70	3.90
PMF (8 mT and 5 min)	2.70	1.30	2.40	5.10	2.00
SMF (19 mT and 15 min)	2.80	2.15	1.61	3.24	3.20
PMF (19 mT and 15 min)	2.00	1.20	1.20	–	2.00
SMF (30 mT and 25 min)	2.96	2.77	2.10	2.80	6.62
PMF (30 mT and 25 min)	3.65	1.95	1.19	–	2.40
AMF (5 mT and 5 min)	4.35	2.17	1.60	3.25	1.22
AMF(9.5 mT and 15 min)	3.09	3.42	2.28	1.90	1.43
AMF (14 mT and 25 min)	2.20	1.40	6.10	2.10	6.00
Blanched	5.10	2.17	3.60	1.25	6.20
Fresh	2.90	1.70	4.40	0.80	2.60

SMF – Static magnetic field; PMF – Pulse magnetic field; AMF – Alternating magnetic field

distribution of freeze-dried winter carrot utilizing the SEM. Moreover, it was reported that no damage was inflicted to the microstructures of apple slices pretreated with osmotic sucrose solution coupled with drying; however, an increase in porosity was observed (Askari et al., 2004).

Elemental distribution of MF pretreated fluted pumpkin leaf

Table 1 presents the elemental distribution in samples at different combinations of the MF pretreatment and comparison of these samples with control samples (blanched and fresh samples). There are variations in the elements in the product at different MF pretreatment combinations. Each MF pretreatment combination led to different values of elements obtained in contrast to other MF pretreatments, as well as to blanched and fresh samples. This observation might be a result of different characteristics of the three types of magnetic field used (Bird, 2010); it is possible that different structures and forms, in which each element naturally exists within the vegetable, have influenced their behaviour in the MF pretreatment; however, the true reason for this might yet to be identified.

Furthermore, from the table, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and iron (Fe) were observed to have the lowest and highest respective values: 1.2–4.35% (fresh – 2.9% and blanched – 5.10%); 1.30–3.42% (fresh – 1.70% and blanched – 2.17%); 1.19–6.10% (fresh – 4.40% and blanched – 3.60%); 0–5.10% (fresh – 0.80% and blanched – 1.25%) and 1.22–6.62% (fresh – 2.60% and blanched – 6.20%). The lowest and highest values of elements in the stated ranges for the MF pretreatment were obtained at SMF (8 mT and 5 min) and AMF (5 mT and 5 min) for Na; PMF (19 mT and 15 min) and AMF (9.5 mT and 15 min) for K; PMF (30 mT and 25 min) and AMF (14 mT and 25 min) for Ca; PMF (19/30 mT and 15/25 min) and PMF (8 mT and 5 min) for Mg and AMF (5 mT and 5 min) and SMF (30 mT and 25 min) for Fe. Dhawi et al. (2009) pretreated the seedlings of date palm with static magnetic field (SMF) of strength from 10 mT to 100 mT for 30–360 min. Date palm leaf elemental analysis utilizing inductive couple plasma (ICP) spectroscopy

showed increase in the concentrations of Ca, Mg, Mn, Fe, Na, K, and Zn; however, phosphorus (P) concentration dropped with increase in SMF strength and exposure time.

Conclusion

Non-thermal magnetic field pretreatment caused various changes in the microstructures of fluted pumpkin leaf. In majority of cases, this consequently led to better retention/improvement of elements (minerals) present in fluted pumpkin leaf in comparison to blanched and fresh samples. The magnetic field pretreatment caused the fluted pumpkin leaf to have 1.3–4.35% sodium (Na); 1.20–3.42% potassium (K); 1.19–6.10% calcium (Ca); 0–5.10% magnesium (Mg) and 1.22–6.62% iron (Fe). Therefore, magnetic field is a possible non-thermal pretreatment alternative that can be explored for the replacement of blanching (a thermal pretreatment). For future research works, shelf life studies of the processed products using different packaging materials and storage conditions, as well as optimization of the process for selection of the best combination of magnetic field pretreatment factors are recommended.

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