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Performance Evaluation of a Laboratory-Scale Magnetic Field Pretreatment Device

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ABSTRACT

Magnetic field as a method of food pretreatment is highly promising due to its non-thermal quality enhancement effects on foods. Magnetic field devices for conducting comprehensive food processing research works are not readily available, especially in developing countries. Also, an in-depth performance evaluation of the few developed magnetic field devices for food processing with a view to knowing the maximum magnetic field strength they can produce seemed not to have been done. Therefore, the objective of this paper was to present the performance evaluation of a laboratory-scale magnetic field device that can be potentially used for food pretreatment. The developed magnetic field device used works on the principle of electromagnetism and it can generate static, pulse and alternating types of magnetic field. It has a transformer designed to step down 240 V supply to 3.20 – 10.10 V for achieving different values of magnetic field strength; eight (8) electromagnets- each electromagnet has 0.3 m magnetic core perimeter and 200 turns of laminated copper wire (1.0 mm^2, 60 m long and 1.2Ω). The performance evaluation of the device indicated approximately 30 mT as its maximum magnetic field strength. Therefore, the device is suitable for food pretreatment in future.

1. INTRODUCTION

Food pretreatment is the process of taking steps to maintain the desired properties of food for as long as possible to ensure the consumption of food with high nutritional values (Rahman and Perera, 2007). Pretreatment is one of the unit operations in food processing and has the tendency of modifying the properties of foods. Food pretreatment can be broadly classified into conventional method and non-conventional (also referred to as novel or emerging technology) method. Some of the examples of the conventional method are pasteurization, sterilization, blanching, parboiling size adjustment, smoking and salting. Typical examples of the non-conventional method are microwave heating, ohmic heating, *sous vide*, pulse electric field, irradiation, high hydrostatic pressure, pulsed light (Neetoo and Chen, 2014) and magnetic field (Ali *et al.*, 2015). Heat application is involved mostly and occasionally in the conventional method and the non-conventional method respectively. The applied heat can sometimes lead to loss of temperature sensitive nutrients of foods. The use of magnetic field for food pretreatment is one of the non-conventional novel methods with non-thermal characteristics, and it is still emerging (Neetoo and Chen, 2014). Emerging non-thermal technologies focus on the production of processed foods of higher quality in contrast to heat-treatment methods (Barbosa-Canovas *et al.*, 2005).

A magnetic field is a space in which a magnetic body is capable of inducing surrounding bodies (Barbosa-Canovas *et al.*, 2005). Magnetic fields are classified as low or high intensity according to their relative strength; as homogeneous or non-homogeneous according to the variation of intensity over space; and as static or pulse according to time interval (Kovacs *et al.*, 1997). The use of magnetic fields as a non-thermal food processing method was first proposed in 1985 (Barbosa-Canovas *et al.*, 2005). The fundamental theory governing the use of a magnetic field for food pretreatment is synonymous with the fact that living cells (foods inclusive) 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 (Dhawi *et al.*, 2009). The interaction between the aforementioned internal and external magnetic fields would cause the naturally unpaired electrons (or scattered ions) of food materials to be rearranged. This will consequently cause the modification of food properties.

Magnetic field technologies in food processing have attracted increased industrial interest because they can replace certain thermal food processing methods (Rahman and Perera, 2007). Hayder *et al.* (2015) used a developed magnetic device for the non-thermal pretreatment of raw milk. The device was reported to have the following components: a milk tank with 5-litre capacity and 10 l/min discharge rate, magnetized milk exit, wooden frame, plastic pipe, switch, two fixed permanent magnets with a distance of 0.5 cm in between them, electric cables, 12 V reciprocating pump, 90 Ah battery and valve. The device produced a static magnetic field (SMF) of strength 0.365 T in between the two fixed permanent magnets arranged in a North-South pattern where the magnetic treatment will take place. The milk pretreated with the device had significant decrease in microbial load, increase in quantity of cheese produced from the magnetized milk and better organoleptic properties than conventional thermally pasteurized milk. Jia *et al.* (2015) developed a magnetic field device for pretreating *Cucumis melo* fruit. The device was made to generate an alternating magnetic field (AMF) of 2 mT field strength. It comprised of a power source, transformer and two parallel couples of Helmholtz coils in addition to a surface between the two coils to hold the fruit to be pretreated. The AMF pretreatment led to reduction in wound responses and better retention of flavor of the fruit. Also, a small-scale magnetic field equipment was developed and used for the sterilization of microbial culture. It produced a pulse magnetic field (PMF) of about 4.5 T field strength. The major components of the equipment were: a pulse magnetic field generator and the sterilization system (Haile *et al.*, 2008). Better microbial sterilization was achieved with the use of the magnetic field equipment. Similarly, Shams *et al.* (2013) reported the pretreatment of oyster mushroom with a developed laboratory-scale magnetic field device. The device produced up to 20 mT static magnetic field strength. The major components of the device were a solenoid, ampere-meter, power supply, voltmeter, rheostat, electric switch, strands of electrical wire for circuit completion and computer for logging and displaying data. A decrease in the concentration of vanadium, mercury, silver and iron with an increase in zinc and lead of the oyster mushroom were achieved after the pretreatment. In addition, a magnetic field system was developed to fractionate Greek yoghurt whey. The device produced a static magnetic field of up to 1 Tesla with permanent magnets. The device has the following major parts: eight (8) neodymium blocks of permanent magnets in two groups of four (4) magnets per group with a space of 2.5 cm apart. Also, it has a holding funnel, steel pipes (1.27 cm inner diameter), a centrifugal pump of 7.5 l/min discharge and a valve (Kyle, 2013). The magnetic field pretreatment led to better retention of the lactose content of the fractionated whey. Furthermore, Lipiec *et al.* (2004) used a developed magnetic field device (with magnetic field strength of 20 T) to test the survival of microorganisms in potatoes. The device consists of the following components: a battery of high-voltage, isolation coil, solenoid of 17 mm internal diameter (magnetic field section), standard test tubes for holding samples to be pretreated, thyristors, resistor, spark gap, power source (0.5 kW), control panel, switch, induction probe with a digital oscilloscope. Bacteria load reduction by 4000 times was achieved after pretreating the sweet potatoes with magnetic field. Ajiboye *et al.* (2021) optimized the design of an electromagnetic coil system. The system can be applied for water treatment, food pretreatment and other suitable purposes. The optimum value of magnetic field strength obtained for the designed system was 0.06 T.

Magnetic field as a method of food pretreatment is highly promising due to its non-thermal quality enhancement effects on foods. However, from the literature, information is scarce on in-depth performance evaluation of magnetic field devices reported for food pretreatment. This situation is causing serious drawbacks to this emerging novel method of food processing in the aspect of not having better understanding of the characteristics of developed magnetic field devices. Therefore, the objective of this study was to carry out an in-depth performance evaluation of a laboratory-scale magnetic field device with a view to knowing the maximum magnetic field strength the device can generate. This will provide useful information on the characteristics of the device for future use as food pretreatment device.

2. MATERIALS AND METHODS

2.1. Description of the MF Pretreatment Device

The MF pretreatment device used (illustrated in Figures 1 and 2) was developed at University of Ilorin, Ilorin, and the Federal University of Technology Akure, Nigeria. It mainly consists of a rectangular pretreatment chamber unit (300 mm x 350 mm x 180 mm) made of aluminium square pipes and a step-down transformer unit. The pretreatment unit has two covered stationary pretreatment boxes (135 mm x 38 mm x 75 mm) made of aluminium for holding the products to be pretreated. Eight electromagnets (four on each side) are properly arranged along the two sides of each pretreatment box. A step-down transformer (from 240 V) together with a rectifier, capacitor, diodes, and timer is connected to the transformer unit. The transformer has tapings for selecting different values of stepped-down voltage (3.20 – 10.10 V) in order to achieve different values of magnetic field strength for pretreatment. The timer is for setting different pretreatment times. The fuse on the plug to be connected to the mains is for the protection of the whole device against damage when there is an electrical surge.

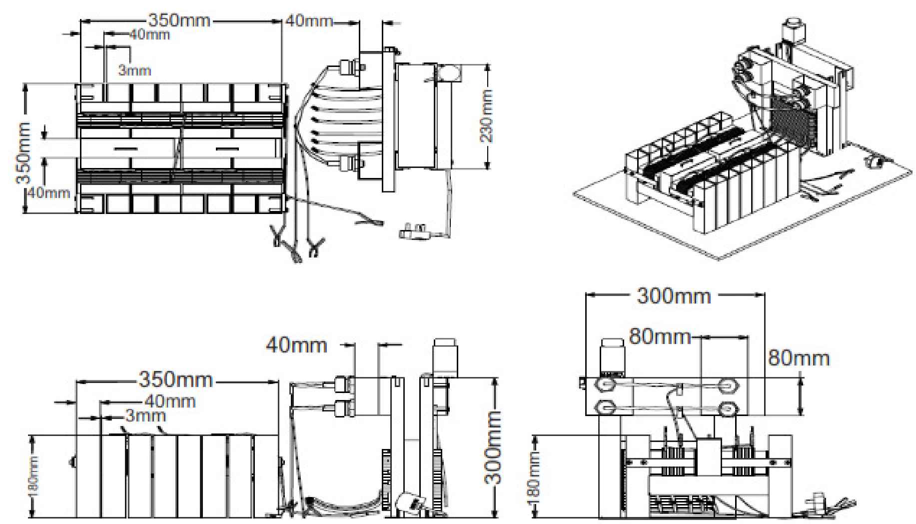
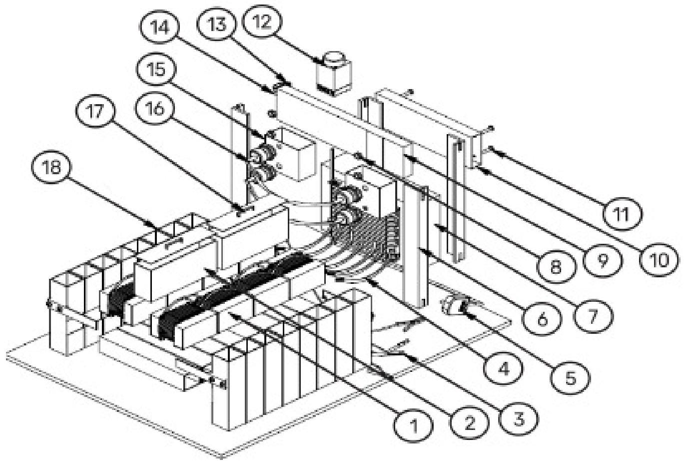


Figure 1: Orthographic and isometric views of the MF pretreatment device



PARTS LIST		
ITEM	QTY	PART NAME
1	8	Electromagnets
2	2	Pretreatment Box
3	4	Crocodile Clip
4	1	Step down voltage terminals
5	1	Mains plug
6	4	Transformer platform
7	1	Step down transformer
8	1	Nuts
9	1	Wooden frame
10	4	Wooden Platform
11	1	Bolt
12	1	Timer
13	1	Capacitor
14	2	Capacitor switch
15	4	Diode platform
16	2	Diode
17	1	Pretreatment box cover
18	1	Pretreatment chamber frame

Figure 2: Exploded view of the MF pretreatment device

2.2. Working Principles of the MF Pretreatment Device

The MF pretreatment device (Figure 3) works on the principle of electromagnetism in which a magnetic field is generated only when current is flowing through the laminated copper wire wound around the magnetic cores of the pretreatment unit. The transformer (TR1) connected to the mains will step down the voltage from 240 V to various levels (SW1) which will be sent to the electromagnets (L1 – L8) arranged along the lengths of the two pretreatment boxes holding the products for the generation of magnetic field strengths (5 - 30 mT). In order to achieve SMF, the current flowing will pass through the rectifier (BR1) and the capacitor (C1) before getting to the pretreatment section. If PMF is needed, the current flowing will only pass through the rectifier before getting to the pretreatment chamber connected to the transformer with a switch (SW2). Also, the current flowing will be made to bypass the capacitor and the rectifier on the transformer in order to obtain the AMF for the pretreatment. The diode (D1) is for the protection of the transformer and its components. A timer connected to the device for setting each pretreatment time (5, 10, 15, 20, and 25 min) automatically stops the operation of the device when the set time expires. This signifies the end of pretreatment time which also protects the device from overworking and increases its user-friendly characteristics. For clarity of information, the wave patterns of SMF, PMF, and AMF are illustrated in Figure 4.

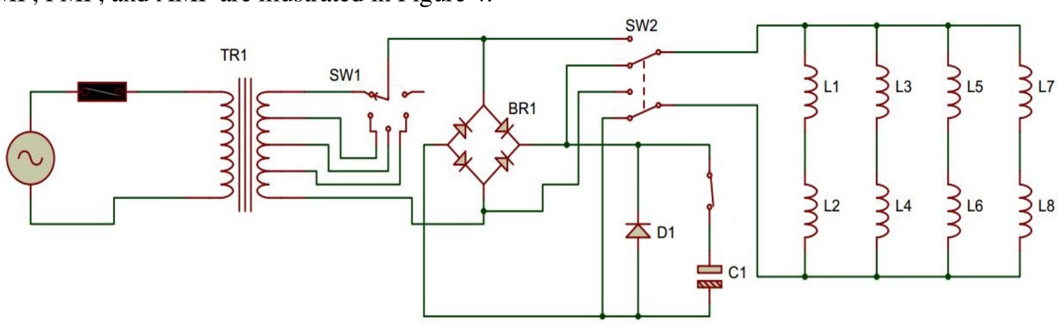


Figure 3: Electrical circuit diagram of the MF pretreatment device

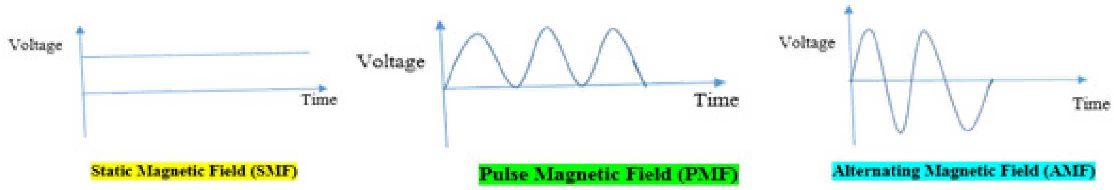


Figure 4: Samples of wave patterns of SMF, PMF, and AMF

2.3. Performance Evaluation of the Magnetic Field Pretreatment Device

Performance evaluation of the device was done after its fabrication and instrumentation (Figure 5). The following instruments were used for the exercise: standard bar magnets (Alnico type, India), Gaussmeter (Model GM-2, ALPHALAB INC., USA), Wattmeter (Model 380940, EXTECH Instruments, USA) and Digital Multimeter (HIOKI DT4282, Japan). Readings of current and voltage from the mains was first recorded as initial values. This was done before and after connecting the transformer unit and the pretreatment chamber unit together. The current was allowed to flow in a way that ensured the electromagnets achieved N-S poles arrangement in the opposite direction; and the poles of the electromagnets were confirmed with the standard bar magnet. Setting of each type of magnetic field (SMF, PMF and AMF) was done on the transformer unit. At each type of magnetic field, the current and voltage, magnetic field strength and power consumed were measured with the multimeter, Gaussmeter and Wattmeter respectively. All readings were repeated ten (10) times and average values were recorded in a tabular form.

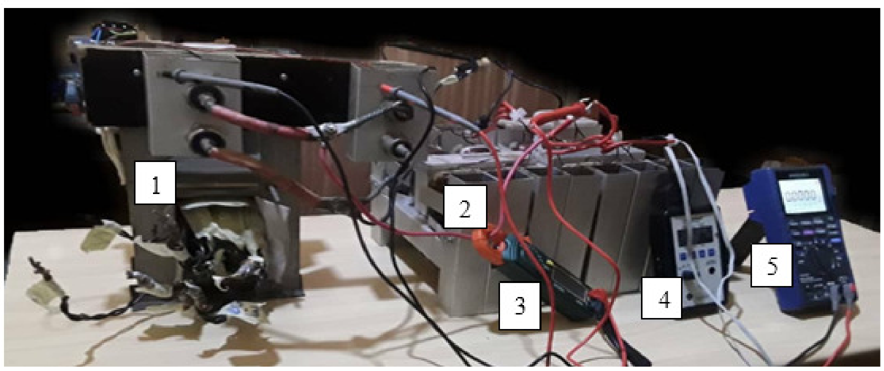


Figure 5: Performance evaluation set-up of the MF pretreatment device

1 – Step-down transformer unit, 2 – Pretreatment chamber unit, 3 – Wattmeter, 4 – Gaussmeter, 5 - Multimeter

3. RESULTS AND DISCUSSION

Tables 1, 2 and 3 show the measured values of parameters during the performance evaluation of the MF pretreatment device for SMF, PMF and AMF respectively. From Tables 1 – 3, an increase in the values of source voltage (when the transformer unit was not connected to the pretreatment chamber unit) from 3.2 to 10.10 V led to increase in voltage readings (when the transformer unit was connected to the pretreatment chamber unit), current, power and magnetic field strength. For SMF, voltage readings, current, power and magnetic field strength increased from 1.36 - 6.14 V, 10.10 - 34.42 A, 120 – 380 W and 8.25 – 32.68 mT respectively with increase in source voltage from 3.2 to 10.10 V. Also, for PMF, voltage readings, current, power and magnetic field strength increased from 1.42 - 6.25 V, 6 - 33.30 A, 150-380 W and 8.38 – 30.35 mT respectively with increase in source voltage. The values obtained under SMF and PMF are relatively close, probably because both are generated by Direct Current (DC) (Bird, 2010), but not the same with AMF (which is from alternating current- AC) that has 3.40 – 10.23V, 3.30 - 9.70 A, 140 – 160 W and 5.67 – 14.38 mT readings with increase in source voltage from 3.20 - 10.10 V. The range of values of magnetic field strength produced by the device in this study was more than the 2 mT generated by the magnetic field device for pretreating *cucumis melo* fruit (Jia *et al*., 2015); but it is within the 20 mT produced by the magnetic field device used for pretreating oyster mushroom (Shams *et al.*, 2013). Furthermore, the power measured did not increase beyond 160 W with increase in source voltage from 6.6 - 10.10 V; similarly, the magnetic field strength did not increase beyond 14.38 mT with increase in source voltage from 8.30 – 10.10 V for AMF (Table 3). This observation might mostly likely be that the saturation point with respect to the properties of the materials used for constructing the electromagnet was reached and no further increase in the values of the source voltage would lead to corresponding increase in the values of magnetic field strength or power (Bird, 2007). Generally, SMF and PMF utilized high currents and low voltage readings than AMF. This observation might be connected to electric power transmission standpoint in which the use of alternating current (AC) was reported as the best means of transmitting power due to low current characteristics in comparison with direct current which utilizes high current (Bird, 2010). Also, low current usually leads to low heating effect and less power requirement. Furthermore, as earlier mentioned, SMF and PMF have closer values and similar trend up to a stage. These observations did not mean that they will have the same effect when used to pretreat foods. Even though they have similar trends in term of the measured values of magnetic field strength, however, their wave patterns (as earlier illustrated in Fig.4) are not the same. This implied that, foods to be pretreated will experience different magnetic field effects even if the values of magnetic field strength of SMF and PMF are the same or very close. This will give different outcomes after food pretreatment (Odewole *et al.*, 2020 and Odewole *et al.*, 2022).

Table 1: Measured parameters of the MF pretreatment device for SMF

Source voltage (V)	Voltage readings (V)	Current (A)	Power (W)	Magnetic field strength (mT)
3.20	1.36	10.10	120.00	8.25
5.00	3.40	14.20	180.00	14.05
6.60	3.74	20.50	240.00	20.05
8.30	4.92	27.50	300.00	26.35
10.10	6.14	34.20	380.00	32.68

Source Voltage: No load voltage of the Step-down Transformer of the MF device; Voltage Readings: On-load voltage obtained from the device (same for current and power); Mains Voltage: 238 - 240 V

Table 2: Measured parameters of the MF pretreatment device for PMF

Source voltage (V)	Voltage readings (V)	Current (A)	Power (W)	Magnetic field strength (mT)
3.20	1.42	6.00	150.00	8.38
5.00	2.69	13.50	200.00	14.58
6.60	3.94	20.50	250.00	20.47
8.30	5.06	27.20	310.00	25.30
10.10	6.25	33.30	380.00	30.35

Table 3: Measured parameters of the MF pretreatment device for AMF

Source voltage (V)	Voltage readings (V)	Current (A)	Power (W)	Magnetic field strength (mT)
3.20	3.40	3.30	140.00	5.67
5.00	5.14	4.90	150.00	9.50
6.60	6.83	6.60	160.00	11.58
8.30	8.52	8.20	160.00	14.38
10.10	10.23	9.70	160.00	14.38

4. CONCLUSION

The performance evaluation of a laboratory scale magnetic field pretreatment device whose parameters can be adjusted to produce SMF, PMF, and AMF was done. The device was able to generate approximately 30 mT as its maximum magnetic field strength. The device can be used to carry out comprehensive magnetic field-related studies on food pretreatment in future.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Ajiboye, A.T., Opadiji, J.F., Popoola, J. O. and Oniyide, O. (2021). Optimum design of square air-core electromagnetic coil system. *FUOYE Journal of Engineering and Technology*, 6(3), pp. 21 - 26.

Ali, H. I., Al-Hilphy, A. R. S. and Al-Darwash, A. K. (2015). The effect of magnetic field treatment on the characteristics and yield of Iraqi local white cheese. *IOSR Journal of Agriculture and Veterinary Science*, 8(9), pp. 63-69.

Barbosa-Canovas, G. V., Swanson, B. G., San Martin, M. F. and Harte, F. (2005). Novel food processing technologies: Use of magnetic fields as a non-thermal technology. *Washington: Marcel Dekker.*

Bird, J. (2010). *Electrical Circuit Theory and Technology*, Fourth Edition, Elsevier Ltd, United Kingdom (UK), pp. 178–179.

Bird, J. (2007). *Electrical and Electronic Principles and Technology*. Third Edition, Published by Elsevier Ltd, pp 71 – 84.

Dhawi, F., Al-Khayri, J. M. and Hassan, E. (2009). Static magnetic field influence on elements composition in date palm (Phoenix dactylifera L.). *Research Journal of Agriculture and Biological Sciences,* 5 (2), pp. 161–166.

Haile, M., Pan, Z., Gao, M. and Luo, L. (2008). Efficacy in microbial sterilization of pulsed magnetic field treatment. *International Journal of Food Engineering*, 4, pp. 1-14.

Hayder, I. A., Asaad, R. S. A. and Amir, K. A. (2015). The effect of magnetic field treatment on the characteristics and yield of Iraqi local white cheese, *IOSR Journal of Agriculture and Veterinary Science* (IOSR-JAVS), 8, pp 63-69.

Jia, J., Wang, X., Lv, J., Gao, S. and Wang, G. (2015). Alternating magnetic field prior to cutting reduces wound responses and maintains fruit quality of cut *cucumis melo L. cv Hetao. The Open Biotechnology Journal*, 9, pp. 230- 235.

Kovacs, P. E., Valentine, R. L. and Alvarez, P. J. J (1997). The Effect of Static Magnetic Fields on Biological Systems: Implications for Enhanced Biodegradation, *Critical Reviews in Environmental Science and Technology*, 27 (4), pp. 319-382.

Kyle, C. (2015). Influence of Magnetic Field Exposure and Clay Mineral Addition on the Fractionation of Greek Yogurt Whey Components. M.Sc. Thesis, Kansas State University, Manhattan, Kansas, USA.

Lipiec, J., Janas, P. and Barabasz, W. (2004). Effect of oscillating magnetic field pulses on the survival of selected microorganisms. *International Agrophysics*, 18, pp. 325–328.

Neetoo, H. and Chen, H. (2014). Food processing: Principles and applications: In S. Clark, S. Jung and B. Lamsal. (2nd Ed.) (137-169). *USA: John Wiley and Sons Limited.*

Odewole, M. M., Olalusi, A. P., Oyerinde, A. S. and Omoba, O. S. (2020). Microstructures and elemental distribution of magnetic field pre-treated fluted pumpkin leaf. *Acta Technologica Agriculturae*, 23(1), pp. 12-17.

Odewole, M. M., Olalusi, A. P., Abdulsalam, K. O. and Hameed, A. G. (2022). Effect of Magnetic Field Pre-treatment on the Fibre Content of Sweet Pepper and Fluted Pumpkin Leaves. *FUOYE Journal of Engineering and Technology (FUOYEJET),* 7(2), pp. 119 – 121.

Rahman, M. S. and Perera, C. O. (2007). *Drying and food preservation*: In M. S. Rahman (2nd Ed.), Handbook of food preservation (403–432). Boca Raton, Florida: CRC PRESS.

Shams, G., Ranjbar, M., Abbasi, A. R., Khodarahmpour, Z., Feizi, H. and Zare, R. (2013). Influence of homogeneous magnetic field on the content of ten trace elements in stipe and cap oyster mushroom (Pleurotus florida). *International Research Journal of Applied and Basic Sciences*, 4 (5), pp. 1071 - 1077.