International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(5): 1208-1214

Received: 15-07-2019
Accepted: 18-08-2019

M Sahithi
M.Tech, Food Process Engineering, Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

Dharini Manoharan
Department of Academics and Human Resource Development Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

Indhumati
Department of Academics and Human Resource Development Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

Shanmugasundaram S
Department of Planning and Monitoring cell, Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

Correspondence
Shanmugasundaram S
Department of Planning and Monitoring cell, Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

Study on disinfestation of processed oats by using Radio frequency technology

M Sahithi, Dharini Manoharan, Indhumati and Shanmugasundaram S

Abstract
The efficiency of Radio frequency sterilizer (RF) to disinfest *Tribolium castaneum* of life stage of Adult in the processed oats has been investigated. A 40MHz, 10kw RF sterilizer with hot-air assisted system is used to conduct the disinfestation studies in oats with and without packaging material. A treatment protocol was set with different electrode height and exposure time for the disinfestation in open tray and HDPE packaging treatment. Changes in moisture content, alcoholic acidity, enzymatic activity, pasting properties are used to evaluate the treatment effect on the product quality for optimization. Results showed that there is significant difference between the packaging in which HDPE showed good results without significant difference of the quality attributes. The 100% mortality of adult insect was achieved with 250 mm electrode height and 11.2 min exposure with no significant difference in the quality attributes. The results suggest that the RF treatment as a post-harvest treatment has the potential for novel disinfestation to control insects in the oats.

Keywords: Hot air radiofrequency, processed oats, exposure time, dielectric disinfestation

Introduction

Oats is ranked sixth after maize, rice, wheat, barley and sorghum in the world's cereal production statistics. Oats have potential anti-cancerous property, (Butt, Tahir-Nadeem, Khan, Shabir, & Butt, 2008) [8]; (Bode & Dong, 2009) [6]; (H.-C. Wang *et al*., 2011) [17], lower blood cholesterol level (Ripsin *et al*., 1992) [44]; (Amundsen, Haugum, & Andersson, 2003) [2]; (Chen *et al*., 2006) [9]. Increase in convenience food consumption and nutritional bioavailability of the oats has led to ready-to-eat breakfast foods (Marathe *et al*., 2013) [29]; (G. Kaur *et al*., 2012) [19]; (Rasane *et al*., 2015) [43]; (Maegli, 1994) [27]; (Slavin *et al*., 2000) [47]. The processed oats are referred as instant oats which are most processed than regular rolled oats. The regular rolled oats are steamed, flaked, dried and cooled. The thickness is about 0.45- 0.60 mm and cooking is less compared to unprocessed oats (Rasane *et al*., 2015) [43].

The oats which are stored during the summer have most chance of getting infested because it is the hottest season of year which makes oats unpalatable due to decrease of specific nutrients. The red flour beetle, *Tribolium castaneum* is the predominant, tolerant insect and most destructive pest among the world and is generally found in stored oat grains (Burkholder and Faustini, 1991) [7]; (Dobie, 1984) [10]; (Appert, 1987) [3]; (Bhargava and Kumawat, 2010) [5]. The disinfestation procedure can be used to reduce the losses due to insects in grain.

The traditional prevention of stored product insects is done by chemical methods by using fumigants such as phosphine, sulphur dioxide, proponic acid, methyl bromide (MB), chlorphyrifos-methyl in which phosphine fumigation is most used method (Kharel *et al*., 2014) [20]. The long term use of fumigants like methyl bromide causes environment pollution like ozone depletion. The usage of synthetic insecticides for food has been limited because of the high safe limits.

The adverse effect caused by chemical disinfestation methods has led to use of thermal disinfestation as alternative method. The heat treatment techniques involve the use of hot air, Infrared heating and Ozone. The use of hot air treatment effects the quality of product (Paull and Armstrong, 1994) [39], and the slow heating rate causes maximum disinclination of conduction in the mass storage which leads to higher time of treatment and loss of quality (Evans *et al*., 1983) [11]. (Beckett and Morton, 2003) [4], by causing the investiture of shock to the insect proteins by heat (Yin, Wang, Tang, Hansen, *et al*., 2006) [54]. Infrared radiation cause moisture losses during disinfestation treatment (Kirkpatrick, 1975; Tilton and Schroeder, 1963) [21, 49].

The major problem involved in the use of heat treatment has led to employ alternative method like dielectric heating. The use of dielectric disinfestation techniques like Radiofrequency and microwave has accomplished results in disinfesting heterogeneous insects in food commodities, fruits, stored grains and vegetables (S.-J. Wang and Tang, 2004) [51]; (Sumnu and Sahin, 2005) [48]; (Marra *et al*, 2009) [30]. The treatment of RF has the advantage over MW as it can penetrate to a greater depth (22 m at 13.56 MHz) compared to MW(0.3 to 7 cm at 2,450 to 915 MHz), because RF has less frequency than MW (Jiao *et al.*, 2011) [17]. The indigenous shallow penetration of MW (Microwave heating) is a momentous restriction for using the microwave technology (Halverson *et al.*, 1996) [16]. The RF simpler in construction, and has higher electric to electromagnetic power conversion, hence can be used for handling bulk samples (Shrestha and Baik, 2013) [46]. The use MW technique has found drawbacks during the disinfestation which made to consider the use of RF technology. The literature has been scanned on the RF technology which has been considered as the feasible solution alternative to other chemical, thermal and techniques. The radiofrequency
(RF) technology involved in usage for drying, sterilization, pasteurization, pre-treatment to drying, product development, extraction of phytochemicals, etc. (Orsat *et al.*, 2007) [37]; (Giri *et al.*, 2007) [15]; (Marra *et al.*, 2009) [30]. All the life stages are ultimately eliminated by using RF technology which leads to volumetric heating in the stored product insects (Shaojin Wang *et al.*, 2010) [53]. The reproductive system of insects are also overblown by using RF technology which is caused by the change in the structure of DNA (Lu HH *et al.*, 2011) [24]; (Lu Huanghua *et al.*, 2010) [23]. The dielectric loss factor of insects is more than the host material in which more energy is absorbed by insects than the product when subjected to alternating electric field thus the quality of the product can be retained (Jiao *et al.*, 2011) [17]; (Shrestha *et al.*, 2013) [46]. (Hung, 2016) [35] has done experiment on rectangular polystyrene container which revealed that dielectric properties and the density of the container influence the heating uniformity. (Alfaifi *et al.*, 2016) [1] has done experiment on the sterilization for insect control in different geometries of package by using RF system with hot air (60 °C) which showed that heating uniformity has also improved by reducing the electrode length than the horizontal dimensions of rectangular container with less damage to the quality in the packaged dried foods. The necessitates of using of Radio frequency without causing effect on quality attributes has led the objective of disinfestation of processed oats with and without packaging material.

2. Materials and Methods

2.1 Procedure of experiment

The processed oats samples procured from the processor with moisture content of 9.86% (w.b) was used for the study. The red flour beetle, (*Tribolium castaneum*) of all life stages of adult was selected for disinfestation studies which are reared on the diet of wheat flour at IIFPT, Tamil Nadu. The culture was maintained at room temperature and adults were collected using standard sieves after 30 days of growth, respectively from the wheat flour. The ten adult insects were introduced into the HDPE package and on open tray each of processed oats samples before the RF treatment.

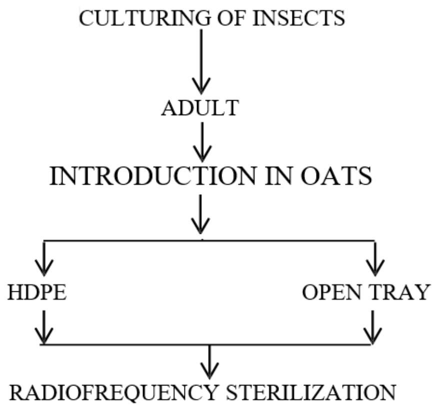


Fig 1: Process flow chart of RF treatment

2.2 Radiofrequency treatment

The RF treatment is conducted using Radio frequency sterilizer (MAKE: Lakshmi INSTA 10/4, INDIA) at Indian Institute of Food Processing Technology. The RF system consists of general assembly, electrode assembly, conveyor assembly, hot air system and control panel. The RF power of 10 KW was applied to disinfest the product at frequency 40.68 MHz ± 0.05 MHz. The RF system consists of general assembly, electrode assembly, conveyor assembly, hot air system and control panel. The spacing of electrodes 180-395mm, conveyor belt width and length of 400mm and 120 mm respectively with conveyor speed of 2.5 - 25 m/hr can be set in HARF. The product is kept on the conveyor belt (400mm length) at different exposure time and passed through an flat electrode system containing 2 flat plate electrodes (top and ground), which is subjected to high RF voltage at a frequency 40.68 MHz (i.e., 40680000 times/second). The electrode height can be adjusted from 180mm-395mm and conveyor speed from 2.5m/hr-25m/hr. A treatment protocol of electrode height (225mm, 250mm, 275mm and 300mm) and exposure time (7.8 min, 8.6 min, 11.2 min and 17.2 min) were adjusted for conducting the treatment.

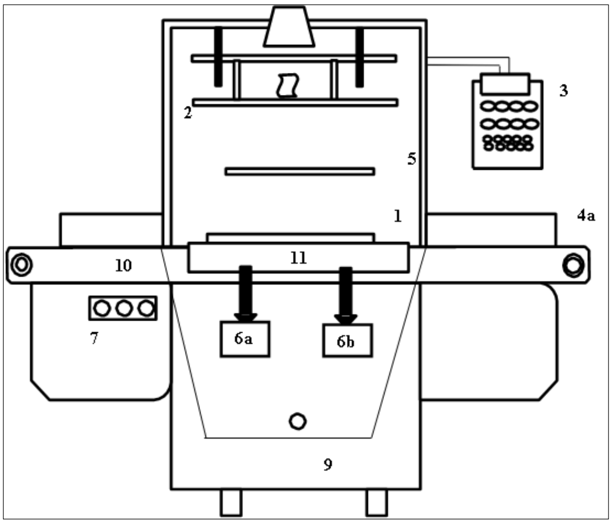


Fig 2: Schematic diagram of hot air assisted RF sterilizer

1. Bottom electrode 2. Top electrode 3. Regulatory system 4. Viewing port 5. Fluorescent tubes 6. Hot-air heating system 7. Radiofrequency switch 8. Air outlet 9. Drying chamber door 10. Conveyor belts 11. Hot air distribution chamber

2.3 Quality analysis
2.3.1 Mortality
The mortality of adult *Triboilium castaneum* in oats at different exposure time and electrode distance was analyzed by considering the number of alive and dead insects after 24hrs by visual observations. The number of dead and live insects were recorded, and expressed in percentage mortality. The insect mortality was calculated by using equation (1) (vadivambal, 2007) [50].

Mortality = …………… (1)

2.3.2 Moisture content
The moisture content of the oats was determined by equation (2) FSSAI (I.S 4333). Sample of 5g of RF treated oats were dried for 2hr in the hot air oven at 1300C, cooled in desiccator containing desiccant and weighed. It is again dried for additional half hour intervals till constant weight is achieved. The observations were recorded and the moisture content on wet basis was calculated using the following formula

Moisture content (M.C.), % = ….. (2)

Whereas,
W1= weight in gms of the dish with the material before drying W2= weight in gms of the dish with the material after drying W = weight in gms of empty dish

2.3.3 Colour
Hunter color lab flex meter (Make; Hunter Association Laboratory, Inc., USA) was used for measurement of color. It provides reading in terms of „L", „a", „b" where; lightness (L) forms the vertical axis, which indicates whiteness to darkness. Chromatic portion of the solids is defined by: a (+red to –green), b (+yellow to –blue). The total colour difference (ΔE) was calculated using the equation (3).

√ …... (3)

2.3.4 Pasting properties
The pasting properties of RF treated samples were analyzed using the rheometer. The pasting properties was widely used to known the oat product quality and it describes the thickness of the oats during cooking (M. Zhou *et al.*, 1998) [55]. A rheometer (Modular compact Rheometer Anton Paar, MCR 52, Austria) with concentric cylinder assembly was used for measurement. The oats samples were sieved for equal particle size and were determined with 3g of sample suspended in 25ml distilled water. After the sample preparation, samples were stirred for 1min and filled in aluminium can. The peak viscosity was recorded from the obtained curve.

2.3.5 Alcoholic acidity
Alcoholic acidity of the RF treated oats was determined by the method (FSSAI 12711:1989). The percentage of alcoholic acidity was calculated using the following formula

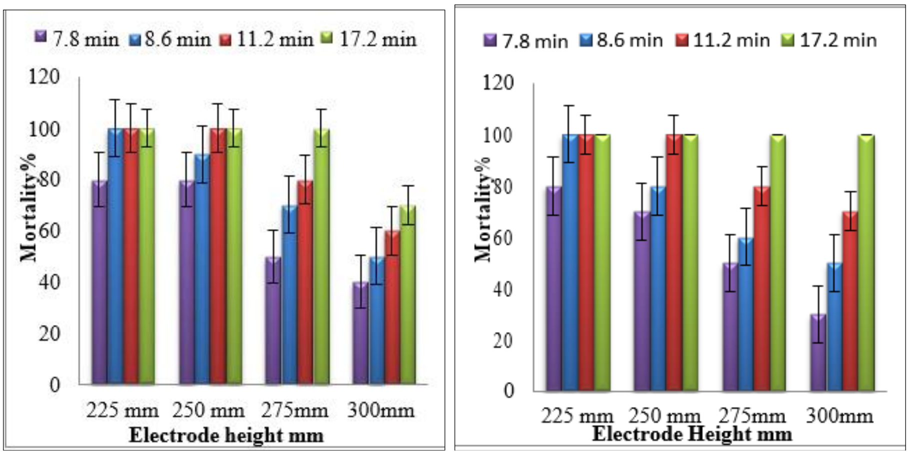
2.3.6 Enzyme activity
Enzyme activity of the RF treated samples was determined by the method AACC (22- 80). The enzymatic activity indicates the presence of peroxidase enzyme in the samples.

2.3.7 Sensory analysis
The sensory evaluation was conducted for the untreated and optimized RF treated oats samples using the 9 point Hedonic scale method.

2.4 Statistical analysis
The is subjected to statistical analysis using CRD ANOVA (AGRESS software, Microsoft excel) for examining the significance of the different electrode height and exposure time of the rolled oats with and without packaging material.

3. Results and Discussion
3.1 Effect of RF treatment on Mortality of insect
The mortality of the processed oats obtained during different process parameters with and without packaging was given in fig.3. From the figure, 100% mortality was observed at minimum exposure time of 8.6 min at electrode height of 225mm for the HDPE and open tray RF treatment. There is no significant difference between the mortality of insects treated with and without packaging but there is significant difference between the process parameters. As the electrode height was increased and exposure time decreased the mortality rate decreased which would have led to increase in the volumetric heating. Similar results were observed by (Jiao *et al.*, 2011) [17].

When the RF is applied, molecules of bipolar substance re-align themselves with above RF field and generate frictional heat within the insect body and insect temperature gets raised. There is a change in DNA structure of the insects, which affects their reproductive behavior which eventually kills the insects (Lu *et al.*, 2010) [25].



(a) (b)

Fig 3: Effect of RF on mortality of Adult insect (a) HDPE (b) Open Tray

3.2 Effect of RF treatment on the moisture content

The effect of electrode height and exposure time on the moisture content of the processed oats is given in fig.4. It was observed from the figure that the moisture content of the RF treated samples ranged between 7.89-9.46% for the HDPE samples and 6.69-8.86% for the samples treated on open trays. It was also found that while increasing the electrode height and decreasing the exposure time there is a decrease in the moisture loss. This may be due to the decrease in the RF density as electrode height increased and exposure time decreased which led to less volumetric heating. Similar results were observed by (Shrestha *et al.*, 2013) [46].

The moisture content with respective to the package, there was less moisture loss of 0.4-1.9 % in the samples treated in the HDPE package compared to samples treated on open trays of 1-3 %. This may be because of the difference in the heating uniformity which was influenced by the dielectric properties and density, geometry of the package. There is significant difference between the moisture content of open tray and HDPE packaging. Similar results were observed by the (Huang *et al.*, 2016) [35] and (Alfaifi *et al.*, 2016) [1]. The more moisture loss was observed in the open trays may be because of the direct exposure of oats. Since the dielectric loss factor of insects is more than the sample, the insect absorb more energy than the sample when subjected to the alternating electric field than the product (Nelson, 2004) [36].

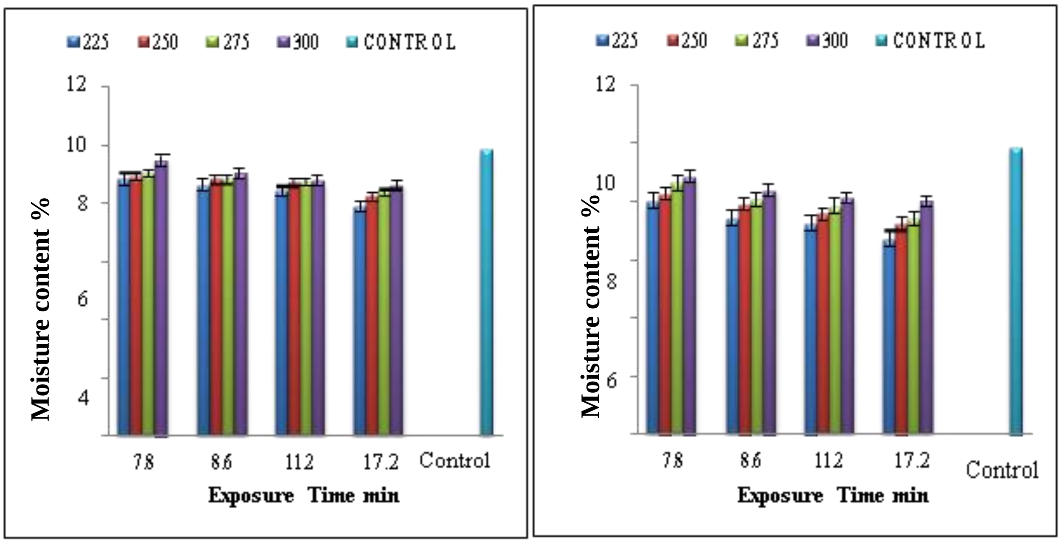
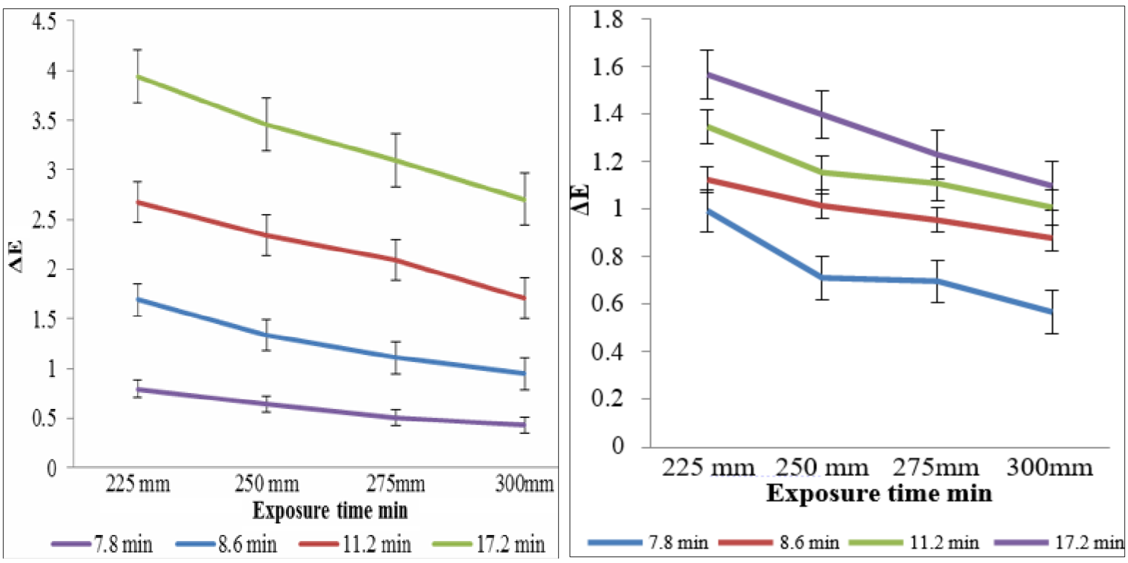


Fig 4: Effect of RF on moisture content (a) HDPE (b) Tray

ΔE of 0.42 and 0.568 is recorded for HDPE and tray samples respectively and 0.568 for tray samples at 300 mm electrode height with 7.8 min exposure time whereas the maximum ΔE value of 1.12 and 1.563 is recorded for HDPE and tray samples respectively at 225mm electrode height and 17.2 min exposure time. It was found that while increasing the electrode height and decreasing the exposure time, the ΔE value was decreased. It was also seen that colour difference was slightly varied for the Tray treated samples and HDPE samples. This may be due to the difference in moisture content of the sample which is influenced by the volumetric heating. Similar results were found by (Jiao *et al.*, 2011) [17]. The statistical results revealed that there is no significant difference in the ΔE value while changing the exposure time, electrode height and packaging material at 5 per cent level.



(a) (b)

Fig 5: Effect of RF on ΔE value (a) HDPE (b) Tray

3.3 Optimization of process parameters
The RF treated samples obtained from 250 mm electrode height for 11.2 min has obtained superior results followed by 225 mm electrode height for 8.6 min and 11.2 min exposure time based upon the 100% mortality with less exposure time, less moisture loss and ΔE value. These three superior resulted combinations have been taken for further quality analysis.

3.4 Effect of RF treatment on pasting properties
The effect of electrode height, exposure time and packaging material on the pasting properties of the RF treated oats is given in Fig 6. The peak viscosity in the pasting profile described the thickness of the oats during cooking (M. Zhou *et al.*, 1998) [55]. It was evident from the figure that peak viscosity was increased for the RF treated HDPE and tray samples compared to the control. It was found that while decreasing in the electrode height and increasing in the exposure time, peak viscosity increased. This may be due to the increase in the intensity of waves as electrode height decreases leads to pre- gelatinization of starch. This starch when dispersed in cold water and heated, more water absorbed and more swelling capacity takes places

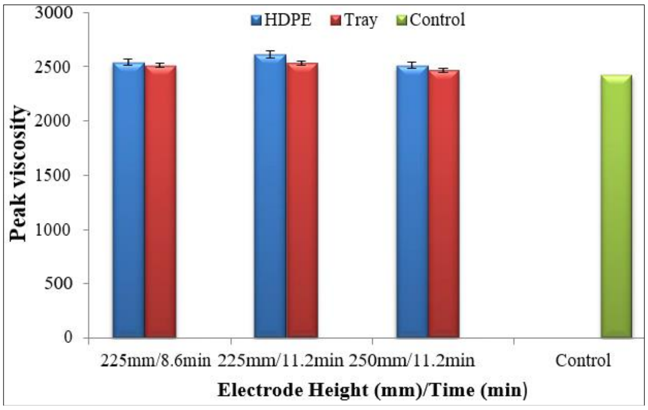


Fig 6: Effect of process parameters and packaging material on the peak viscosity of processed Oats

Which leads to increase in viscosity. Similar results were absorbed by (Ovando-Martínez *et al.*, 2013) [38] (Ghiasi *et al.*, 1982) [14] and (Ragaee and Abdel-Aal, 2006) [41]. The statistical results revealed that there is significant difference in the viscosity while changing the exposure time, electrode height and but there is no significant difference in the viscosity treated with different packaging material at 5 per cent level. It was also found that 250mm electrode height with 11.2 min exposure time has less peak viscosity of 2512 cP for HDPE and 2465 cP for tray. It was evident from the figure that HDPE packed RF treated samples recorded high peak viscosity compared to tray may be because of the less moisture content of samples may increase the swelling capacity of granules which leads to high viscosity.

3.4.1 Effect of RF treatment on alcoholic acidity
The effect of electrode height, exposure time and packaging material on the pasting properties of the RF treated oats is given in Fig 7. It was observed that as the electrode height decreases and the time increases there was an increase in the alcoholic acidity than the control. The alcoholic acidity is directly proportional to the deterioration of the samples in which the RF treated samples has similar values as the control which is in safe limit i.e, below 8ml.

It was recorded that HDPE samples at 250mm electrode height and 11.2 min exposure time recorded has least alcoholic acidity of 0.17 ml and the highest value was found at 225 mm electrode height of 11.2 min exposure time of 0.198 ml. This may be due to the less moisture content of samples which results that their no hydrolysis of fats by lipase into free fatty acids and hydrolysis of proteins into amino acids by proteolytic enzymes. Hence, it shows that samples did not undergo any type of deterioration after the RF treatment. Similar results were observed by (Frankel, 1984) [13]. The statistical results revealed that there is no significant difference in the alcoholic acidity value while changing the exposure time, electrode height and packaging material at 5 per cent level.

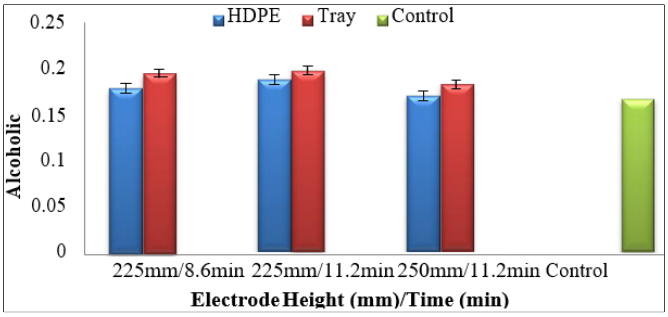


Fig: 7 Effect of process parameters on the alcoholic acidity of processed Oats

3.5.1 Effect of RF on enzymatic activity
The effect of electrode height, exposure time and packaging material on the pasting properties of the RF treated oats is given in Table 1. The results reported that, all the RF treated samples has negative values which indicates the adequate heat processing of the samples. This may be due to inactivation of the peroxide enzymes which is more thermal stable than lipase enzyme for maintenance of adequate flavor in the samples. Similar results were observed for the dielectric heating of cereals by (Fang *et al.*, 2008) [12] and (Malekian, 1992) [28].

Table 1: Effect of process parameters and packaging on the enzymatic activity of processed oats

Electrode height mm	Exposure time Min	Enzymatic activity	
		HDPE	**Tray**
Control		Negative	Negative
225	8.6	Negative	Negative
	11.2	Negative	Negative
250	11.2	Negative	Negative

3.5.6 Sensory evaluation
The sensory evaluation has been conducted for the optimized parameters for varieties of oats treated with and without packaging material. The effect of the RF variables on the sensory parameters of the processed oats was given in Fig 8. The optimized RF samples treated in HDPE and Tray samples at electrode height 250 mm with 11.2 min exposure time were accepted according to the scores given by the panelists for the Aroma, Taste, Chewability, Pastiness, and overall acceptability. The HDPE samples gave equal acceptance as control compared to the tray samples in terms of Taste and overall acceptability. The score of 8 is given to the RF treated HDPE samples is equal to the score for control sample i.e "Like Very Much".

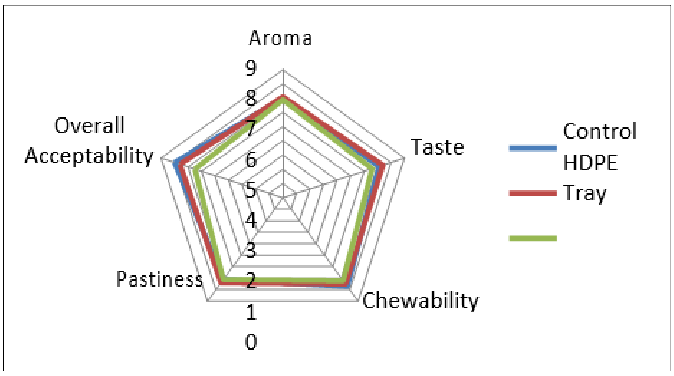


Fig 8: Effect of RF treatment on the sensory quality of the processed oats

Conclusion

The current study has provided the optimized condition of radio frequency sterilizer for 100% mortality without affecting the product quality of processed plain oats using HDPE package and without packaging as the dielectric loss factor of the insect is more than product in the Radio frequency sterilizer by maintaining heating uniformity using the hot air assisted Radiofrequency sterilizer. The experiment showed that there is significant difference between quality parameters of the open treatment and the HDPE package. The HDPE package attained no significant changes of quality parameters when electrode height and exposure time of 250 mm and 11.2 min respectively. As the electrode height increases and the exposure time decreases which gives less effect of the product quality. This study helps in industrial-scale disinfestation which can be used alternative to the chemical fumigation.

References

1. Alfaifi B, Tang J, Rasco B, Wang S, Sablani S. Computer simulation analyses to improve radio frequency (RF) heating uniformity in dried fruits for insect control. Innovative Food Science & Emerging Technologies. 2016; 37:125-137.
2. Amundsen AL, Haugum B, Andersson H. Changes in serum cholesterol and sterol metabolites after intake of products enriched with an oat bran concentrate within a controlled diet. Scandinavian Journal of Nutrition. 2003; 47(2):68-74.
3. Appert J. The storage of food grains and seeds: Macmillan Publishers, 1987.
4. Beckett SJ, Morton R. Mortality of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) at grain temperatures ranging from 50 C to 60 C obtained at different rates of heating in a spouted bed. Journal of Stored Products Research. 2003; 39(3):313-332.
5. Bhargava M, Kumawat K. Pests of stored grains and their management: New India Publishing, 2010.
6. Bode AM, Dong Z. Cancer prevention research-then and now. Nature Reviews Cancer. 2009; 9(7):508.
7. Burkholder W, Faustini D. Biological methods of survey and control. Ecology and management of food industry pests. 1991; 361-372.
8. Butt MS, Tahir-Nadeem M, Khan MKI, Shabir R, Butt MS. Oat: unique among the cereals. European journal of nutrition. 2008; 47(2):68-79.
9. Chen J, He J, Wildman R, Reynolds K, Streiffer R, Whelton P *et al*. A randomized controlled trial of dietary fiber intake on serum lipids. European journal of clinical nutrition. 2006; 60(1):62.
10. Dobie P. Biological methods for integrated control of insects and mites in tropical stored products. I: The use of resistant varieties. Tropical Stored Products Information (UK), 1984.
11. Evans DE, Thorpe GR, Dermott T. The disinfestation of wheat in a continuous- flow fluidized bed. Journal of Stored Products Research. 1983; 19(3):125-137.
12. Fang L, Jiang B, Zhang T. Effect of combined high pressure and thermal treatment on kiwifruit peroxidase. Food Chemistry. 2008; 109(4):802-807.
13. Frankel E. Lipid oxidation: mechanisms, products and biological significance. Journal of the American Oil Chemists' Society. 1984; 61(12):1908-1917
14. Ghiasi K, Varriano-Marston K, Hoseney RC. Gelatinization of wheat starch. II. Starch-surfactant interaction. Cereal Chem. 1982; 59(2):86-88.
15. Giri S, Mohapatra D, Prasad S, Sutar P. Radio Frequency Heating Applications in Food Processing and Packaging Industries. Packaging India. 2007; 39(6):23.
16. Halverson SL, Burkholder WE, Bigelow TS, Nordheim EV, Misenheimer ME. High-power microwave radiation as an alternative insect control method for stored products. Journal of economic entomology. 1996; 89(6):1638-1648.
17. Jiao S, Johnson JA, Tang J, Tiwari G, Wang S. Dielectric properties of cowpea weevil, black-eyed peas and mung beans with respect to the development of radio frequency heat treatments. Bio systems engineering. 2011; 108:280-291.
18. Jiao S, Johnson JA, Tang J, Wang S. Industrial-scale radio frequency treatments for insect control in lentils. Journal of Stored Products Research. 2012; 48:43-148.
19. Kaur G, Sharma S, Nagi H, Dar BN. Functional properties of pasta enriched with variable cereal brans. Journal of food science and technology. 2012; 49(4):467-474
20. Kharel K, Arthur FH, Zhu KY, Campbell JF, Subramanyam B. Evaluation of synergized pyrethrin aerosol for control of Tribolium castaneum and Tribolium confusum (Coleoptera: Tenebrionidae). Journal of economic entomology. 2014; 107(1):462-468.
21. Kirkpatrick RL, Cagle A. Controlling insects in bulk wheat with infrared radiation. Journal of the Kansas Entomological Society. 1978; 386-393.
22. Kirkpatrick RL. Infrared radiation for control of lesser grain borers and rice weevils in bulk wheat (Coleoptera: Bostrichidae & Curculionidae). Journal of the Kansas Entomological Society. 1975; 100-104.
23. Lu HH, Zhou JC, Xiong SB, Zhao SM. Effects of low intensity microwave radiation on *Tribolium castaneum* physiological and biochemical characteristics and survival. Journal of Insect Physiology. 2010; 56:1356
24. Lu HH, Zhou JC, Yan D, Zhao SM, Xiong SB. Effects of microwave radiation and conductive heating on Tribolium castaneum microstructure. Micra. 2011; 42:36 -4
25. Lu H, Zhou J, Xiong S, Zhao S. Effects of low-intensity microwave radiation on Tribolium castaneum physiological and biochemical characteristics and survival. Journal of insect physiology. 2010; 56(9):1356-1361.
26. MacDougall DB, Granov M. Relationship between ultraviolet and visible spectra in Maillard reactions and CIELAB colour space and visual appearance. In The Maillard reaction in foods and medicine. 1998; 160-165.

27. Maegli JW. Seasoned snack foods and methods for production thereof: Google Patents, 1994.
28. Malekian F. Functional, nutritional and storage characteristics of rice bran as affected by microwave heat and extrusion stabilization methods, 1992.
29. Marathe NP, Rasane MH, Kumar H, Patwardhan AA, Shouche YS, Diwanay SS. *In vitro* antibacterial activity of Tabernaemontana alternifolia (Roxb) stem bark aqueous extracts against clinical isolates of methicillin resistant Staphylococcus aureus. Annals of clinical microbiology and antimicrobials. 2013; 12(1):26.
30. Marra F, Zhang L, Lyng JG. Radio frequency treatment of foods: review of recent advances. Journal of Food Engineering. 2009; 91(4):497-508.
31. Mitcham EJ, Veltman RH, Feng X, De Castro E, Johnson JA, Simpson TL *et al*. Application of radio frequency treatments to control insects in in-shell walnuts. Postharvest Biology and Technology. 2004; 33(1):93-100.
32. Mohapatra D, Giri S, Kar A. Effect of microwave aided disinfestation of Callosobruchus maculatus on green gram quality. International Journal of Agriculture and Food Science Technology. 2014; 5(2):55-62.
33. Mohapatra D, Mishra S, Singh CB, Jayas DS. Post-harvest processing of banana: opportunities and challenges. Food and bioprocess technology. 2011; 4(3):327-339.
34. Morris VJ. Starch gelation and retrogradation. Trends in Food Science & Technology. 1990; 1:2-6.
35. Nagaraj G, Purohit A, Harrison M, Singh R, Hung YC, Mohan A. Radiofrequency pasteurization of inoculated ground beef homogenate. Food control. 2016; 59:59-67.
36. Nelson SO. Review and assessment of Radio-Frequency and Microwave energy for stored-grain insect control, T ASAE. 1996; 39(49):1475-1484.
37. Orsat V, Yang W, Changrue V, Raghavan G. Microwave-assisted drying of biomaterials. Food and Bioproducts Processing. 2007; 85(3):255-263.
38. Ovando-Martínez M, Whitney K, Reuhs BL, Doehlert DC, Simsek S. Effect of hydrothermal treatment on physicochemical and digestibility properties of oat starch. Food research international. 2013; 52(1):17-25.
39. Paull RE, Armstrong JW. Insect pests and fresh horticultural products. Treatments and responses, 1994.
40. Purohit P, Jayas DS, Yadav BK, Chelladurai V, Fields PG, White NDG *et al*. Microwaves to control Callosobruchus maculatus in stored mung bean (Vigna radiata). Journal of stored products research. 2013; 53:19-22.
41. Ragaee S, Abdel-Aal ESM. Pasting properties of starch and protein in selected cereals and quality of their food products. Food chemistry. 2006; 95(1):9-18.
42. Rani MS, Bhattacharya KR. Rheology of Rice-Flour Pastes: Effect, of Variety, Concentration, and Temperature and Time of Cooking. Journal of Texture Studies. 1989; 20(2):127-137.
43. Rasane P, Jha A, Sabikhi L, Kumar A, Unnikrishnan V. Nutritional advantages of oats and opportunities for its processing as value added foods-a review. Journal of food science and technology. 2015; 52(2):662-675.
44. Ripsin CM, Keenan JM, Jacobs DR, Elmer PJ, Welch RR, Van Horn L *et al*. Oat products and lipid lowering: a meta-analysis. Jama. 1992; 267(24):3317-3325.
45. Sacchetti G, Pinnavaia GG, Guidolin E, Dalla Rosa M. Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products. Food Research International. 2004; 37(5):527-534.
46. Shrestha B, Baik OD. Radio frequency selective heating of stored-grain insects at 27.12 MHz: a feasibility study. Bio systems engineering. 2013; 114:195-204.
47. Slavin JL, Jacobs D, Marquart L. Grain processing and nutrition. Critical Reviews in Food Science and Nutrition. 2000, 40(4):309-326.
48. Sumnu G, Sahin S. Recent developments in microwave heating. In D.-W. Sun (Ed.), emerging technologies for food processing San Diego: Elsevier. 2005; 419-444.
49. Tilton EW, Schroeder HW. Some effects of infrared irradiation on the mortality of immature insects in kernels of rough rice. Journal of Economic Entomology. 1963; 56(6):727-730.
50. Vadivambal R, Jayas DS, White NDG. Determination of mortality of life stages of Tribolium castaneum (Coleoptera: Tenebrionidae) in stored barley using microwaves. Journal of Economic Entomology. 2007; 101(3):1011-1021.
51. Wang S, Tang J. Radiofrequency heating: a potential method for post-harvest pest control in nuts and dry products. Journal of Zhejiang University. Science. 2004; 5:1169-1174.
52. Wang S, Monzon M, Johnson JA, Mitcham EJ, Tang J. Industrial-scale radio frequency treatments for insect control in walnuts: I: Heating uniformity and energy efficiency. Postharvest Biology and Technology. 2007; 45(2):240-246.
53. Wang S, Tiwari G, Jiao S, Johnson JA, Tang J. Developing postharvest disinfestation treatments for legumes using radio frequency energy, Biosyst. Eng. 2010; 105:341-349.
54. Yin X, Wang S, Tang J, Hansen JD, Lurie S. Thermal conditioning of fifth-instar Cydia pomonella (Lepidoptera: Tortricidae) affects HSP70 accumulation and insect mortality. Physiological Entomology. 2006; 31(3):241-247.
55. Zhou M, Robards K, Glennie-Holmes M, Helliwell S. Structure and pasting properties of oat starch. Cereal Chemistry. 1998; 75(3):273-281.