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Research Article

PERFORMANCE EVALUATION OF PULSED MAGNETIC FIELD SYSTEM FOR THE TREATMENT OF ORANGE JUICE

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Abstract: Pulsed magnetic field processing is a novel method of food preservation which involves the use of magnetic field in the form of pulses with varying frequency. Pulsed magnetic field treatment was given to orange juice at different concentration for inactivating the microorganism and for retaining the quality parameters during storage period. A laboratory model batch type Pulsed magnetic field treatment chamber was designed. To evaluate the efficiency of the system, the different process parameters were selected *i.e.*, magnetic field intensity (2T, 4T and 6T), Concentration of fruit juice (10, 15 and 20%) and treatment time (5, 10 and 15 min). The process parameters had significant effect ($p<0.01$) on microbial destruction, viscosity and colour value of orange juice. Log reduction for TPC was found to be maximum of 2.28 and for yeast and mold reduction was found to be 1.02 for fruit juice subjecting to 4T magnetic field with 15 min treatment time stored under refrigerated condition for about 10 days.

Keywords: *Pulsed magnetic field, Orange juice, Non-thermal method, Microbial inactivation, Process parameter*

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Introduction

Fruits impart a positive impact on the wellbeing of humans which should be included in our diet due to the presence of some bioactive compounds such as tocopherols, carotenoids, polyphenols, phenolics, anthocyanins, vitamins and minerals[1].Fruits are processed into fruit juices as they are highly preferred by consumers of all age groups. Fruit juices are the source of antioxidants, vitamin C, Vitamin E, minerals, fibre and organic acids which influence much impact on human health [2]. Consumption of fruit juice has increased in the recent years because it reduces the risk of diseases and improves human health [3]. Orange juice was considered to be well accepted by consumers and its consumption statistics increases steadily and considered to be prominent juice by beverage processing industry. Orange juice contains some volatile compounds responsible for flavor and it changes according to storage time and temperature conditions [4]. Recently consumers demand for safe and minimally processed foods with high quality attributes with minimum change induced by technologies themselves which paved the way for non thermal processing [2]. Alternative to thermal processing is the non thermal technologies which provides high quality and environmental friendly food which paved the way for commercialization[6] with product safety requirement [7]. Fruit juice becomes the host for the growth of micro organism as they provide sufficient nutrition for the growth and multiplication of microbes causing the spoilage of products. So by adopting non thermal preservation techniques such as Pulsed electric field, High Pressure Processing, Cold Plasma, Ultrasound and Pulsed magnetic field processing the spoilage of fruit juices can be prevented. Among those non thermal treatments, Pulsed Magnetic Field processing is gaining importance nowadays. Pulsed magnetic field sterilization known as Cold pasteurization technology was initially used for sterilization of circulating water in air conditioning refrigeration system but the main constraint is that applied discharge voltage is too high which is difficult for operation [8].

By reducing and regulating the voltage fluctuation this system can be commercialized. The product that is to be sterilized using Pulsed magnetic field requires no special preparation, no added chemicals and it can be treated at atmospheric temperature and pressure to attain sterility. The major requirement being that materials with low electrical conductivity or high resistivity are subjected to high intensity low frequency oscillating magnetic field produced by the solenoid coil by induced eddy current for a short period of time which leads to destruction of microbes without affecting the nature of the product.

Materials and Methods

Extraction of Orange juice

The Mandarin oranges (Ooty) were purchased from the local market (Coimbatore, Tamil Nadu, and India). They were visually inspected for separating damaged and good ones. The selected oranges were cut into two halves with a knife and were hand pressed against a citrus juice press (Philips HR2771 0.5 L citrus press, Philips India Ltd., India). Seed and pulp were retained in the sieve provided in juicer. The filtered juice gets collected at the bottom cup of the juicer which is then taken in sterile bottle for further processing.

Design of batch type pulsed magnetic field system

The PMF generation circuit consist of four minor circuits namely power supply unit, PIC microcontroller unit, MOSFET driver unit and Inverter circuit which are interconnected. The Power supply for the driver circuit unit and PIC microcontroller was given by four transformers. From transformer T1, 230V AC power supply was stepped down to 15V AC which is then converted to DC with the help of Bridge rectifier. The converted DC supply was then connected to 5V potentiometer switch and LCD display through PIC microcontroller.

Table-1 *ANOVA for pH,Viscosity, L value and b value of pulsed magnetic field treated orange juice during storage period*

Variables	pH		Viscosity		L value		b value	
	C.D	S.E.D	C.D	S.E.D	C.D	S.E.D	C.D	S.E.D
F	0.0215	0.0080	0.0001	0.00005	0.02573	0.00963	0.0183	0.0068
T	0.0215	0.0080	0.0001	0.00005	0.02573	0.00963	0.0183	0.0068
C	0.0215	0.0080	0.0001	0.00005	0.02573	0.00963	0.0183	0.0068
F×T	0.0372	0.0139	0.0002	0.00008	0.04456	0.01668	0.0317	0.0118
T×C	0.0372	0.0139	0.0002	0.00008	0.04456	0.01668	0.0317	0.0118
F×C	0.0372	0.0139	0.0002	0.00008	0.04456	0.01668	0.0317	0.0118
F×T×C	0.0645	0.0241	0.0003	0.00014	0.07719	0.02889	0.0549	0.0205

Table-2 *Effect of pulsed magnetic field treatment on total plate count in orange juice*

B(T)	T (min)	Concentration (%)					
		10%		15%		20%	
		1st day	10th day	1st day	10th day	1st day	10th day
	5	$1.65x10^4$	$3.43 x10^4$	$2.29 x10^4$	$3.32 x10^4$	$2.08 x10^4$	$3.42 x10^4$
2	10	$1.87 x10^4$	$2.93 x10^4$	$2.1 x10^4$	$3.0 x10^4$	$1.91 x10^4$	$2.76 x10^4$
	15	$1.39 x10^4$	$2.11 x10^4$	$1.55 x10^4$	$2.34 x10^4$	$1.19 x10^4$	$1.93 x10^4$
	5	$1.68 x10^4$	$2.73 x10^4$	$2.09 x10^4$	$2.53 x10^4$	$1.93 x10^4$	$2.36 x10^4$
4	10	$1.78 x10^4$	$2.59 x10^4$	$1.81 x10^4$	$2.48 x10^4$	$1.8 x10^4$	$2.18 x10^4$
	15	$1.1 x10^4$	$1.82 x10^4$	$1.43 x10^4$	$1.86 x10^4$	$1.35 x10^4$	$1.44 x10^4$
	5	$2.48 x10^4$	$3.79 x10^4$	$2.12 x10^4$	$3.62 x10^4$	$2.54 x10^4$	$4.01 x10^4$
6	10	$2.67 x10^4$	$3.26 x10^4$	$2.3 x10^4$	$3.54 x10^4$	$2.43 x10^4$	$2.98 x10^4$
	15	$2.06 x10^4$	$2.43 x10^4$	$2.261 x10^4$	$2.71 x10^4$	$1.97 x10^4$	$2.04 x10^4$

Table-3 *Effect of pulsed magnetic field treatment on yeast and mold present in orange juice*

B(T)	T (min)	Yeast and Mold cfu/ml					
		10%		15%		20%	
		1st day	10th day	1st day	10th day	1st day	10th day
	5	$1.88 x 10^4$	$3.26 x 10^4$	$1.92 x 10^4$	$3.46 x 10^4$	$1.68 x 10^4$	$3.67 x 10^4$
2	10	$2.29 x 10^4$	$2.95 x 10^4$	$2.01 x 10^4$	$2.98 x 10^4$	$1.67 x 10^4$	$2.88 x 10^4$
	15	$1.95 x 10^4$	$2.44 x 10^4$	$1.71 x 10^4$	$2.67 x 10^4$	$1.65 x 10^4$	$1.96 x 10^4$
	5	$2.03 x 10^4$	$2.56 x 10^4$	$1.88 x 10^4$	$2.03 x 10^4$	$1.78 x 10^4$	$1.93 x 10^4$
4	10	$2.34 x 10^4$	$2.54 x 10^4$	$1.85 x 10^4$	$2.01 x 10^4$	$1.85 x 10^4$	$1.89 x 10^4$
	15	$2.12 x 10^4$	$2.45 x 10^4$	$1.94 x 10^4$	$2.25 x 10^4$	$1.68 x 10^4$	$1.78 x 10^4$
	5	$2.07 x 10^4$	$3.68 x 10^4$	$1.87 x 10^4$	$2.66 x 10^4$	$1.82 x 10^4$	$3.52 x 10^4$
6	10	$2.05 x 10^4$	$3.15 x 10^4$	$2.18 x 10^4$	$2.94 x 10^4$	$1.83 x 10^4$	$2.84 x 10^4$
	15	$2.15 x 10^4$	$2.48 x 10^4$	$1.83 x 10^4$	$2.64 x 10^4$	$1.84 x 10^4$	$2.1 x 10^4$

From transformer T2, T3 and T4, power supply was given to voltage regulator through 1000µF/35V capacitor. An unregulated voltage VIN was filtered by 1000 µF capacitor and connected to Pin 1 of voltage regulator. Pin 3 of IC was connected to the output which provides 15V voltage filtered through 10µF capacitor. This output voltage was given as input voltage to operate MOSFET driver unit. This driver unit was connected to the gate and source terminals of the MOSFET switches. The current from these switches were made to pass through the series resonant circuit consisting of capacitors and inductor coil. Capacitors blocks the DC current and allows AC current. By varying the input current in the system magnetic field intensity can be varied. Input current was measured in terms of voltage by the oscilloscope. The terminals from the oscilloscope were connected through 1 ohm resistor. By ohms law voltage is proportional to current (V=IR; since R=1, V=R). Magnetic field produced in the solenoid coil can be calculated using the formula (B = (µnI)/l).

Physico- Chemical Properties

pH

pH is the measure of acidity or alkalinity of the liquids. The pH of orange juices was determined using pocket pH meter (pHep, Hanna Instrument Inc., Woonsocket, AI02895, USA). The bulb was washed with distilled water and checked with buffer solution and it was standardized at 7. Then it was inserted into juice three replicate readings are taken and mean values were reported [9].

Colour

Colour is considered to be one of the factor that affects the consumer purchase behavior. Colour of fruit juice can be measured using Hunter colour lab (Hunter Lab Colourimeter, Miniscan XE Plus Hunter Associates Lab inc., Reston, Virginia, USA). The principle behind this colourimeter is that it measures the energy reflected from the sample across the entire visible spectrum. Colourimeter can be expressed in terms of Lab value where 'L' stands for level of lightness /darkness of sample, 'a'- value for redness or greenness, 'b'- value represents the yellowness or blueness of sample. Initially before starting the experiment equipment's get standardized using the black and white tiles provided.

Viscosity

Viscosity refers to the thickness of the fluid (*i.e.*) resistance of any liquid to flow which occurs due to friction between molecules in the liquid. Viscosity reduces with increases in temperature. Viscosity can be measured using rheometer and the value of viscosity was determined for different concentration during storage period.

Microbial Analysis

Initially untreated fruit juice samples were observed for bacterial and fungal growth by Standard plate count method. Then treatments were given for fruit juice by non thermal pulsed magnetic field system and the samples of different dilutions were analysed for about 10 days under refrigerated condition in a period of interval of two days.

Enumeration of bacteria, Yeast and Mold in fruit juices

Initially dilutions were taken upto 10^{-6} and they are prepared using sterile water. 1ml of fruit juice was taken and it was pipetted into 9 ml of sterile water contained in the test tube and then shaken well for even distribution which was taken as 10^{-1} dilution. 1 ml from 10^{-1} dilution was transferred into 9ml of sterile water test tube taken as 10^{-2} dilution. The same process gets repeated till 10^{-6} dilution. For enumeration of bacteria, sample dilution of 10^{-5} and 10^{-6} were taken in sterile petri plates and three replications were maintained for obtaining the bacterial counts and for yeast and mold enumeration 10^{-1} and10^{-2} were taken in sterile petri plates. Media used for bacteria enumeration was Nutrient Agar medium and for yeast and

mold enumeration Rose Bengal Agar medium was used. For about 15-20 ml molten and cooled media was poured into sterile Petri plates along with the samples and they were rotated in clockwise and anticlockwise direction for complete mixing of samples. These Petri plates were incubated for about two days for bacterial count and three days for yeast and mold count afterwhich colony forming units were counted for both bacteria and yeast.

$$No\ of\ colony\ forming\ units/g\ of\ samples\ = \frac{No\ of\ colony\ forming\ units\ \times\ Dilution\ factor}{Quantity\ of\ samples\ on\ weight\ basis}$$

Statistical analysis:
The statistical tool used for analysis of PMF system is 3 factor completely randomized design and number of experiments conducted is 27. Level of significance and interaction effect of dependent and independent variables were analysed by performing ANOVA method and optimized parameters after statistical analysis were used for conducting the storage study after Pulsed Magnetic Field treatment.

Results and Discussion

Effect of pH, Viscosity and colour value of orange juice after PMF treatment
pH of orange juice decreases with increase in magnetic field intensity and storage period and increases with treatment time and TSS. pH decreases due to biochemical reaction together with microbial action in fruit juice. pH of orange juice did not have any significant difference after PMF treatment. L and b value increases with increase in concentration and decreases with increase in storage period irrespective of concentration. Viscosity increases with increase in treatment time and TSS and decreases with storage time.

Effect of pulsed magnetic field treatment on total plate count and yeast and mold count of orange juice
The total plate count of PMF treated orange juice is given in the [Table-1]. From the table it is clear that less colony forming of 1.1 x 10^4 cfu/ml and 1.35 x 10^4 was observed in PMF treated juices for about 15 minutes with magnetic field intensity of 4T. The obtained results were better only for the products which are exposed to magnetic field for a longer period. [Table-1] gives the mean value of colony forming unit of 102 and 103 dilution after Pulsed Magnetic field treatment. Colony forming unit decreases with increase in treatment time and magnetic field intensity upto certain point after which it has no effect and colony forming unit increases with increase in storage time. TPC of orange juice gradually increases over the period of storage. Magnetic field decreased the bacterial growth rate when microorganism was exposed for longer period but becomes resistant if exposed too long and process considered to be bacterial[10-12]. Haile *et al*., 2008 [5] found that at low intensities, the survival rate of microorganism decreased and reached minimum. By increasing the intensity, the survival rate gets decreased and at maximum intensity it gets decreased again. Thus, effectiveness in sterilisation rely on intensity and species of bacteria. From the table, it can be inferred that yeast and mold of orange juice with 20% concentration subjected to 4 T magnetic field for 15 minutes was found to have less colony forming unit of 1.68 x10^4 cfu/ml. Orange juice with 10 % concentration subjected to 4 T magnetic field for 10 minutes was found to have higher colony forming unit of 2.34x10^4 cfu/ml. Colony forming unit decreases with increase in TSS, treatment time and magnetic field intensity upto certain point after which it has no effect and Colony forming unit decreases with increase in storage time. Yeast and mold present in orange juice gradually increases over the period of storage. From the [Table-2], it can be inferred that orange juice at 20 % concentration treated with 4T Magnetic field intensity for 15 minutes gave the best treatment effect on the reduction in the yeast and mold present in orange juice. Lipiec *et al*., 2004[13] reported that exposing the fungi in liquid nutrient medium to 20T magnetic field for about 250-350 seconds which reduced the colony 30 times compared with control (2 order in magnitude). The absence of mycelial growth rate in yeast and mold may be due to long time exposure to magnetic field [14]. Novickij *et al*., 2014 [15] reported that higher Pulsed magnetic fields have significant sensitizing effect on salt stressed fungi because of oxidative stress induced in cells which reduces colony forming units. Sterilization effect was better for bacteria when compared with yeast and mold. Reason is that cellulosic cell wall of yeast and mold was stronger than bacteria so that tolerating ability is high [8]. the results obtained are in accordance with PMF treated orange juice.

Conclusion

Treating the orange juice with pulsed magnetic field intensity of 4T for 15 minutes and 20 % concentration had produced better quality samples in terms of pH, viscosity, colour value and microbial reduction. Hence, it can be recommended for processing of high acid fruit juices.

Table-4 *ANOVA for Total plate count and Yeast and Mold Count of Pulsed Magnetic Field treated orange juice during storage period*

Variables	Total Plate Count		Yeast and Mold count	
	C.D	S.E.D	C.D	S.E.D
F	0.03693	0.0133	0.03328	0.01201
T	0.03693	0.0133	0.03328	0.01201
C	0.03693	0.0133	0.03328	0.01201
F×T	0.06396	0.02308	0.05764	0.0208
T×C	0.06396	0.02308	0.05764	0.0208
F×C	0.06396	0.02308	0.05764	0.0208
F×T×C	0.11078	0.03998	0.09983	0.03603

Application of Research: It is a novel method for processing and preservation of fruit juices with minimal quality changes.

Research category: Non thermal technology.

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Research project name: M.Tech- Pulsed Magnetic Field Treatment of Fruit Juices.

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Study area / Sample Collection: Local market, Coimbatore

Cultivar / Variety name: Mandarin orange

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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