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Advances in post-harvest pest control in agricultural commodities: A review

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Abstract
The purpose of this review is to represent the alternative thermal method of insect control i.e. electromagnetic wave's energy. It became very essential to focus other ways of pest control, as already investigated that chemical fumigation control insect but they are harmful for human health and also for our environment, also in some way they are not residue free. It also investigated that conventional heating method uses high temperature (nearly 40 to 55 °C) for achieving complete mortality and produces thermal degradation, affecting also various quality parameters. Alternatively to reduce temperature to avoid thermal degradation increases treatment duration. So here, it has been discussed other electromagnetic waves research studies and its efficacy. Future research studies must be focussed on combination of conventional and electromagnetic heating so that pest control would be more safe and economical without affecting the quality parameters.

Keywords: fumigation, dielectric heating, electromagnetic radiation, solar energy.

1. Introduction

Heat is always associated with development of human societies but until modern era it is used only for cooking and food preservation. In modern era it has been used for post-harvest treatment i.e. specially for pest control, since previously pests are tolerated due to limited transportation and limited production. Recent agricultural technology has provided surplus production which has been stored for future consumption and transportation also predominant due to search of better market for good value of product. Therefore, methods are felt necessary which may control the increasing population and wide distribution of pest which has developed some action such as inspection, surveillance, and testing or treatment process collectively known as phytosanitation. Initially heat treatment is widely applicable and energy source is needed for this purpose. It can range from simple open flame, dry heat, steam, and forced hot air commonly called convention heating methods to complex form of electromagnetic radiation such as radio frequency, microwave or infrared commonly called dielectric heating. It is important to note that thermal treatment must be precise due to narrow margin between efficacy and commodities tolerance to temperature, especially in the case of fruits and vegetables, i.e. when heat is used for pest control pest must be more sensitive to the treatment as compared to commodities ((Tang *et al*,. 2000; Wang and Tang, 2001) [34, 35]. The benefits from pest control must warrant the potential costs from thermal damage such as dehydration, loss of cellular membrane integrity, cellular leakage, disruption of protein and nucleic acid synthesis, inhibition of pigment synthesis, formation of surface burns, increased transpiration, and advanced senescence (Kays and Paul, 2004) [8].

2. Thermal treatment response

A very little review is available which explain what actually causes thermal death. Thermal death mechanism may involve denaturation or coagulation of proteins (Larsen, 1943; Rosenberg *et al*., 1971; Kampina, 2006) [11, 23, 7] or damage to the cell wall (Bowler 1987) [3]. Humidity (Mellanby 1932) [14], degree of starvation (Mellanby, 1934) [15], temperature acclimation (Mellanby 1954) [16], or age (Bowler, 1967; Boina and Subramanyam, 2004) [2, 30] may affect the thermal death point. Insects cease their activity by going into heat stupor due to exposure to sublethal high temperatures (Klok and Chown, 2001; Slabber and Chown, 2005) [9, 27]. Thermal treatment may also encourage the pest to move to another location and out of the treatment area, which may be useful when managing structural pests.

3. Conventional Heating

Chemical fumigant (methyl bromide and phosphine), Methyl bromide gas eventually enters the atmosphere during aeration, which results in depleting the ozone layer. Its use has been scheduled to be phased out in developed countries by 2005 and developing countries by 2015 according to the Montreal Protocol. Phosphine fumigation is problematic because the gas corrodes copper, gold and silver, and can seriously damage electrical equipment. Therefore there is need for alternative and so conventional heating method is increasingly popular due to alternative of chemical fumigation. It includes several methods among which forced hot air and hot water is more popular and predominantly used as these methods are simple to use and also easily controlled. The fruit core should reach at prominent temperature for effective result. Slow heating rate results into longer treatment times. These heating methods have certain limitations due to heat convection from the medium to the surface and from the surface to the fruit core. The heating time can be slightly decreased by increasing the air speed. Furthermore, external and internal damage caused by heat over long exposure times included peel browning, pitting, poor colour development and abnormal softening (Lurie, 1998) [12] and prolonged heating may not be practical in industry applications. Therefore, dielectric heat treatments have become new initiatives to achieve the same level of insect mortality at a shorter time and also fulfil the industrial purposes.

Table 1: Temperature characteristics of conventional heating methods

Medium temp., °C	Heating methods	Fruit types	Speed, nos'	Core temp., °C	Needed time, min
40	Hot air	Apple	1	40	360
44	Moist air	Apple	2	42	97
45	Hot air	Tangerine	2	44	60
45	Hot air	Cherry	2	44	23
48	Hot water	Small Potato	2	48	140
48	Hot water	Large Potato	2	48	220
48	Hot water	Grapefruit	2	48	155
50	Hot air	Mango	2	48	150
52	Hot air	Mango	2.5	39	75
52	Hot air	Grapefruit	2	48	90

(Source: Agricultural Engineering Journal 2001, 10(3&4): 105-120)

4. Properties of Dielectric Heating

Dielectric heating is based on the dielectric properties difference, the differential heating between the target insects and host products. Various researches has observed that this heating method resulted in the insects reaching a lethal temperature while the product is heated to lower temperatures that do not cause quality loss (Wang *et al*., 2001a, 2010; Hou *et al*., 2014) [36, 5]. There is need to explore differential heating, the time and the product temperature needed for effective treatments could be significantly reduced, thereby reducing adverse effects on product quality and enabling a greater throughput of product in a processing plant (Shresth and Baik, 2013; Wang *et al*., 2013) [26, 39]. There are several factors which influence the dielectric heating of agricultural products. However, the major factors are dielectric properties of agricultural products and distribution of electromagnetic fields, which determine the thermal energy in agricultural products converted from electromagnetic energy. This energy generates heat volumetrically and rapidly within agricultural products by the combined effects of polarization mechanisms of dipole rotation and ionic conduction, which are discussed in below section.

(A) Dielectric Properties

Mostly, agricultural products act as an electric capacitor and resistor to store electrical energy and to transform electric energy into thermal energy respectively, thereby heating the products. The ability to gain heat is defined by dielectric properties (ε) normally described by the following equation (Risman, 1991) [23]:

$$\varepsilon = \varepsilon' - j\varepsilon''$$

Where, $j = \sqrt{-1}$. ε is the relative dielectric constant, and describes the ability of a material to store energy in response to an applied electric field (for a vacuum $\varepsilon' = 1$). ε'' is relative electric loss factor, and describes the ability of a material to dissipate energy in response to an applied electric field, which typically results in heat generation. Dielectric properties of agricultural products depend on the frequency of electromagnetic field, temperature, moisture content, density, and composition of agricultural products (Nelson and Trabelsi, 2012) [19].

Table 2: Dielectric properties of typical agricultural products at three temperatures and two frequencies

Material	M.C (WB %)	Tem(°C)	Dielectric constant		Loss factor		Penetration depth		source
			27.12MHz	912 MHz	27.12MHz	912 MHz	27.12MHz	912 MHz	
Wheat	11	25	4.8	3.7	4.2	1.7	99	9	Nelson and Trabelsi (2006) [19]
		75	14.9	8.4	7.3	2.2	96	7	
		95	63.6	22.3	67.5	7.3	23	3	
Soybean	8	24	3.1	-	0.3	-	1035	-	Nelson and Charity (1972) [18]
Apple	85	25	93.2	59.3	213.4	7.5	11	5	Wang *et al*. (2003b)
		45	103.7	61.8	317.8	7.2	8	6	
		65	117.5	64.6	405.1	7.7	7	7	

(B) Power density

The power absorbed in a unit volume of a dielectric material depends on its dielectric properties (the loss factor) and can be expressed as below (Ryynänen, 1995)

$$P_v = 2\pi \varepsilon_o \varepsilon'' V^2$$

where P_v is the power conversion per unit volume (W/m^3), f is the frequency of electromagnetic field (Hz), ε_o represents the dielectric constant in vacuum (8.854 x 10^{-12} F/m), and E is the electric intensity in agricultural products (V/m).

Above equation represents that the power absorbed in a dielectric material is linearly proportional to the frequency, the relative dielectric loss factor and the square of the electric intensity. When the loss factor is between 2 and 100, it is effective to heat material with dielectric heating technology. Large loss factor would result in small penetration depths, which cause only skin heating. On the other hand, small loss factor means that the material, such as air and deionized water, is transparent to the electromagnetic wave (Orsat *et al*., 2001) [20]. Thus, dielectric properties are essential parameters when assessing the feasibility of dielectric heating.

(C) Penetration depth

The penetration depth (d_p, m) of a material is defined as the depth below the surface of a material where the power density of a perpendicularly impinging, forward propagating electromagnetic wave has diminished by 1/e (e = 1/2.7188, 37%) from the surface value (Risman, 1991) [23]. The penetration depth is calculated as (von Hippel, 1954) [36]:

$$d_p = \frac{c}{2\sqrt{2}\,\pi f\left[\varepsilon'\sqrt{1+(\frac{\varepsilon'}{\varepsilon''})^2}\ -1\right]^{1/2}}$$

where c is the speed of light in free space (3 x 10^8 m/s). From above equation it is clear that the penetration depth of a material is inversely proportional to the frequency as the dielectric properties are fixed.

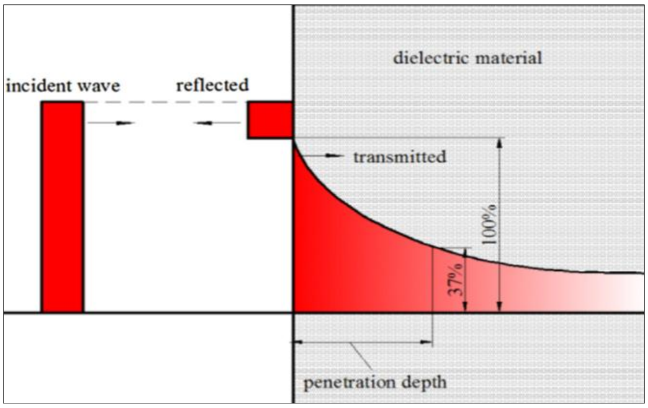

Fig 1: Power flow when an electromagnetic wave strikes a dielectric material with high loss factor (Laborelec 2011) [7]

5. Electromagnetic energies

(A) Infrared

Infrared radiation extends from the nominal red edge of the visible spectrum at 700 nano-meters (nm) to 1 millimetre (mm). This range of wavelengths corresponds to the frequency 0.3 to 430 THz, between visible light and microwaves. Infrared radiation is strongly emitted by hot substances and is readily absorbed by living tissue. Thus, it is logical that infrared radiation has been examined as a thermal treatment. Schroeder and Tilton (1961) [25] reported complete control of rice weevils and lesser grain borers with infrared exposures of less than a minute and at mean temperatures of 568C and 688C, respectively. Tilton and Schroeder (1963) [33] examined the rate of adult emergence of rice weevils, lesser grain borers, and Angoumois grain moths from rice by temperatures produced by infrared radiation. More recently, Subramanyam (2004, 2005b) [30, 31] reported mortality from flameless catalytic infrared heaters on adults of the sawtoothed grain beetle, rice weevil, red flour beetle, lesser grain borer However, research and application of infrared technologies have not been popular in recent decades.

(B) Microwave

Microwaves are electromagnetic waves with frequencies ranging from about 300MHz to 300GHz and corresponding wavelengths from 1 to 0.001m. Researchers have reported that microwave treatment is an attractive post harvest insect control treatment. The major advantage of microwave heating is that it interacts directly with food grains and significantly reduces the amount of time required for food grain to reach the lethal temperature for insects as compared with conventional heating methods. It has been studied that the chemical and biochemical changes during microwave treatment of wheat and reported that an improvement in the baking quality was found at higher energy doses and higher product temperatures (Kaasova *et al*., 2002) [6] The decrease in germination capacity/seedling viability was related to the final temperature and the initial moisture content of the grains. (Locatelli and Traversa, 1989) [4] have reported that temperature of grain has to reach 80◦C for achieving complete mortality of insects using microwave. In fact, most infesting biological agents do not survive over a certain temperature called lethal temperature, generally between 55 ◦C and 60 ◦C, which can be rapidly reached through microwave irradiation (Fields, 1992) [21]. Life stages of the insect have been investigated which is most susceptible to microwave energy at 28GHz frequency (Halverson *et al*, 2003) [42]. The life stages tested were egg, young larva, and pupa. It has been found that egg and young larva of all were always more susceptible than the pupa. We have seen above that microwaves energy have potential for disinfestations applications in the grain industry but still they have not been used widely due to their adverse effects on various quality parameters. The major problems associated with microwave heating are the non-uniform temperature distribution and thereby incomplete kill of microbes (Ryynanen *et. al*., 2001 Geedipalli *et. al*., 2007) [28, 29]. Hot spots (local area of very high temperature) have been developed on products due to the non-uniform heating pattern of microwaves; play an important role for the quality degradation of products. (Manickavasagan *et al*., 2007) [1] Had determined the germination percentage of microwave-treated wheat samples collected from hot-spot and normal heating zones. The wheat samples having four different moisture levels (12%, 15%, 18%, and 21% wb) were subjected to different microwave treatments (100, 200, 300, 400, and 500 watt with exposure times of 28 and 56 s) in continuous industrial microwave dryer (2450MHz). The germination percentage of the sample in the hot-spot region was significantly lower than that of the normal heating region for all moisture and power levels. The microwave's intensity diminishes with increased penetration. It has been reported that microwave treatment of bulk grain is not feasible when the depth is greater than 4 inch (Vadivambal, 2009) [25]. Due to the limited penetration of microwave energy, it seems that employment of microwave radiation alone could not be considered as a promising insect control measure under field condition. Disinfestations of stored products using microwaves energy coupled with other modes of treatment can be an alternative measure in killing insects effectively, but little work has been reported on combined application. Combined application of microwaves with hot-air treatment/ cold storage/gamma radiation could be considered as a potential measure which can help reduce stored-product insect's population.

(C) Radio frequency
Three radio frequencies are recognized in the USA for industrial purposes: 13.56 + 0.067 MHz, 27.12 + 0.60 MHz and 40.68 + 0.020 MHz (Wang *et al*., 2001b) [40]. Radio frequencies generate internal heat by resistance from the very rapid change in molecular polarity. The advantages of radio frequency heating are that it is very fast, can penetrate deep into the target material because of its longer wavelength, may produce possible differential heating between the product and the pest, and does not produce toxic residues. Wang *et al*. (2005) [41] developed a mathematical model that described internal heating of in-shell walnuts for insect pest control. In 2005, the commercial feasibility of radio frequency methodologies to control stored product pests of walnuts was demonstrated at a walnut packing house (Wang *et al*. 2005) [41]. Mirhoseini *et al*. (2009) [14] tested the efficacy of 13.56, 27.12, and 40.68 MHz against the confused flour bettle and the rice weevil, and they reported that pest control potency and intensity increased as radio frequency increased.

(D) Solar
Solar energy has been investigated as a thermal treatment. Compared to the other methods, this is a relatively recent procedure. In India, Chauhan and Gaffer (2002) [7] developed a solar heating method using clear polyethylene bags for control of Callosobruchus spp. in pigeonpea.

6. Conclusion
Postharvest treatments are essentially required to completely control insect pests before the products are moved through marketing channels to areas where the pests do not occur. Several methods have been suggested to control insect pests in agricultural commodities, including chemical fumigation, thermal treatment, ionizing radiation, cold storage, controlled atmospheres, dielectric heating, and combination treatments. Current technologies do not involve the use of toxic chemicals which is neither consumer friendly nor environmentally friendly and conventional thermal methods are either undesirable or cause loss of volatile components, browning, and texture change. Several researches has been done on irradiation technologies especially on microwaves, considered as safe and competitive alternative method to other pest control methods and can avoid problems of food safety and environmental pollution. It has been found that that complete mortality, that is, 100%, could be achieved using microwave energy. Non- uniform heating and hot spot development are measure drawbacks as it affect he various quality parameters. Therefore new research areas should be focussed on minimization of uniform heating, its efficacy and make this more economical so that it may serve as prominent alternative method for maintain the safe insect control and quality parameters.

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