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Effect of fruit fly (*B. dorsalis*) infestation on the thermal emissivity of mango fruits

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Abstract
Mango fruit fly (*B. dorsalis*) is a major pest in mango, which causes a substantial economic loss to the tune of 27 – 80 percent at the pre-harvest and post-harvest stage of mango production. Mango varieties such as 'Banganpalli', 'Alphonso' and 'Totapuri' are most susceptible to fruit fly infestation. Therefore, mango fruit fly is considered as a pest of quarantine importance in the mango trade. The engineering properties of foods invariably influence the quality of food products in terms of visual characteristics and basic functionality. The internal and external characteristics such as size, shape, colour, weight, specific gravity, % T A, pH, TSS, volatile compounds, carotenoids, vitamins and volatile compounds determine the quality of mango fruits. Emissivity is one of the thermal property which attribute the quality of food materials. Emissivity is defined as the ratio of energy emitted from an object to that of a black body at the same temperature. The thermal emissivity of healthy and fruit fly infested mango fruits of the varieties 'Alphonso' and 'Totapuri' was determined using thermal imaging technique. It was found that there was significant difference in the thermal emissivity of healthy and fruit fly infested fruits at the same heating conditions due to the changes in internal structure and composition of fruit fly infested mango fruits. It was also observed that, there was variation in thermal emissivity between the varieties which may attributed to the difference in the varietal characteristics such as peel thickness and pulp content of 'Alphonso' and 'Totapuri' mango fruits.

Keywords: Fruit fly, fruit quality, mango, texture and thermal emissivity

Introduction
Mango (*Mangifera indica*) is one of the most relished fruit crops of tropical and sub-tropical regions, known for its rich aromatic flavor, succulent and delicious taste. India is the major producer of mango with a share of 40% global production [3]. There are about 250 insects, and mite pests reported in mango fruits [16]. Out of these, *Bactrocera dorsalis* (Hendel) is an economically important pest capable of causing considerable loss in yield to the tune of 27 – 80 percent at pre-harvest and post-harvest stage of mango production [1]. Mango varieties such as 'Banganpalli', 'Alphonso' and 'Totapuri' are most susceptible to fruit fly infestation [8]. The adult females of fruitflies (*B. dorsalis)* puncture the fruit peel and lay 10-50 eggs in clusters beneath the skin of mature and ripening mango fruits. During this process, there is a release of volatile compounds and enhanced enzymatic activity, which causes physicochemical changes in fruit fly infested fruits [14]. The eggs hatch within 1-2 days, and the larvae feed on the fruit pulp and contaminating it with frass and providing entry for symbiotic bacteria.
Textural properties such as peel firmness and pulp firmness attribute to the external characteristics of mango. In fresh fruits, the presence of fruit fly infestation decreased the peel firmness and pulp firmness by 46% and 54%, respectively [11]. Thermal properties such as thermal conductivity and thermal diffusivity are influenced by fruit fly (*B. dorsalis)* infestation in mango fruits [15]. In fresh fruits, significant physicochemical changes were observed due to fruit fly infestation [13]. The surface characteristics such as surface finish, color, texture, grain, and even tone influence the emissivity value of wood [12].
The internal and external characteristics determine the quality of mango fruits. The engineering properties of foods determine the quality of food material in terms of visual characteristics and basic functionality. One of the thermal properties of food materials attributed to the quality of food material is its thermal property. Emissivity is defined as the ratio of energy emitted from an object to that of a black body at the same temperature. Emissivity ranges from 0-1; the emissivity of perfect white body and black body is 0 and 1,

respectively. The total amount of energy emitted by any object can be calculated using a thermal camera within the wavelength of 8-12µm using Stefan-Boltzmann law, as given below.

$$W = \sigma \varepsilon T^4 \quad (1)$$

Where
W = total amount of energy emitted from the target (W m^{-2});
σ = Stefan-Boltzmann constant (5.67×10^{-8} Wm^{-2} K^{-4})
ε = the emissivity of the target
T = the temperature of the target (K).

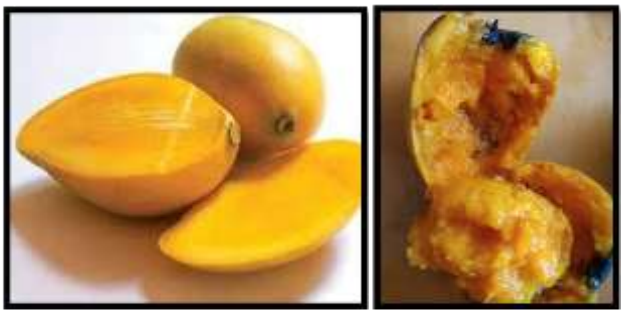
Emissivity can be categorized into spectral emissivity and hemispherical or total emissivity. Total emissivity is determined in the case of heat transfer studies. Total emissivity is a surface property of the material influenced by a depth of only a few microns from the surface. Emissivity is dictated by its surface temperature [6]. Thermal imaging is a non-destructive and non-interactive technique that is widely used in thermometry and various applications in agricultural engineering, especially in food materials at the post-harvest stage [7; 5].

The thermal emissivity of metals is quite low, but non-metals have comparatively higher thermal emissivity values [4]. Emissivity values for various materials such as wood, water, and other non-metals are available in literature ranges from 0.8-0.95 [10]. However, meager information is available on the thermal emissivity of fruits, especially healthy/uninfested and fruit fly infested mango fruits. Therefore, the present study was undertaken to investigate the effect of fruit fly infestation on the thermal emissivity of healthy and fruit fly infested mango fruits.

Materials and Methods

Sample preparation

The mature mango fruits of 'Alphonso' and 'Totapuri' variety were harvested from the research farm of UAHS, Shivamogga, Karnataka, India. The harvested fruits were artificially ripened before conducting the experiments. The ripe mango fruits of both varieties were artificially infested for fruitflies under laboratory conditions. The experiments consisted of Randomized Complete Block Design (RCBD) with three replications to obtain the thermal emissivity of uninfested/healthy and fruit fly infested fruits. The uninfested/healthy and fruit fly infested mango fruits are shown in Fig.1a and Fig.1.b, respectively.



a. Healthy **b.** Fruit fly infested

Fig 1: Mango fruits

Thermal emissivity

The thermal emissivity of healthy and fruit fly infested mango was determined by thermal imaging technique [9; 17]. The fruit samples were heated gradually from room temperature to 50°C, and then the temperature of one random point on the fruit was measured using a contact thermometer. Simultaneously, a thermal camera (Model: C3 Thermal Camera, make: FLIR Systems) with an 80x60 IR sensor operating from 7.5 to 14.0µm spectral range was focused as close as possible to the same spot where the contact thermometer was placed. The emissivity was allotted different values in the camera until the thermal camera read the same temperature as the contact thermometer, as shown in Fig. 2

Fig 2: Experimental setup for determination of thermal emissivity using thermal imaging technique.

Statistical Analysis

The data on the thermal emissivity of uninfested/healthy and fruit fly infested mango under different heating conditions were statistically analyzed by ANOVA in Systat software.

Results and Discussion

The experimental results of the average thermal emissivity of healthy and fruit fly infested mango fruit from three replications are given in Table 1. It was observed from the experimental results that the thermal emissivity of uninfested /healthy mango was significantly higher compared to fruit fly infested mango for both the varieties.

The emissivity values of mango fruits varied from 0.96-0.93 and 0.92-0.89 for uninfested/healthy and fruit fly infested fruits of 'Alphonso' varieties and similarly varied from 0.92-0.95 and 0.87-0.90 for uninfested/healthy and fruit fly infested fruits of 'Totapuri' variety respectively. The variation in thermal emissivity of healthy and fruit fly infested mango fruits with an increase in temperature is shown in Fig. 3 and Fig. 4. It was observed that the thermal emissivity of uninfested/healthy and fruit fly infested mango fruits of both varieties decreased with an increase in temperature. The significant difference in the variation of thermal emissivity between healthy and fruit fly infested fruits at the same heating conditions was observed probably due to the changes in internal structure and composition of fruit fly infested mango fruits. Earlier studies have shown the changes in the chemical parameters such as TSS, pH, % T. A in fruit fly infested mango fruits, a reduction in pH and TSS and an increase in % T.A. was observed in fruit fly infested mango fruits compared to the uninfested fruits [2].

The statistical analysis showed a significant difference (P< 0.05) in thermal emissivity between uninfested/heathy and fruit fly infested mango fruits for both the varieties. Also, a significant difference ($P < 0.05$) was observed in thermal emissivity between the varieties, possibly due to the difference in the varietal characteristics such as peel thickness and pulp.

The presence of fruit fly larvae in fruits causes several changes in internal quality parameters such as the TSS, pH, % T.A., and the internal damage area. While pH and TSS decreased with storage time, % T.A. increased with storage time compared with the fruits under controlled conditions.

Table 1: Thermal emissivity of mango fruits

Variety	Thermal emissivity(ε)			
	Uninfested/healthy fruits		Fruit fly infested fruits	
	45°C	50 °C	45°C	50°C
Alphonso	0.95	0.93	0.90	0.89
Totapuri	0.94	0.92	0.88	0.87

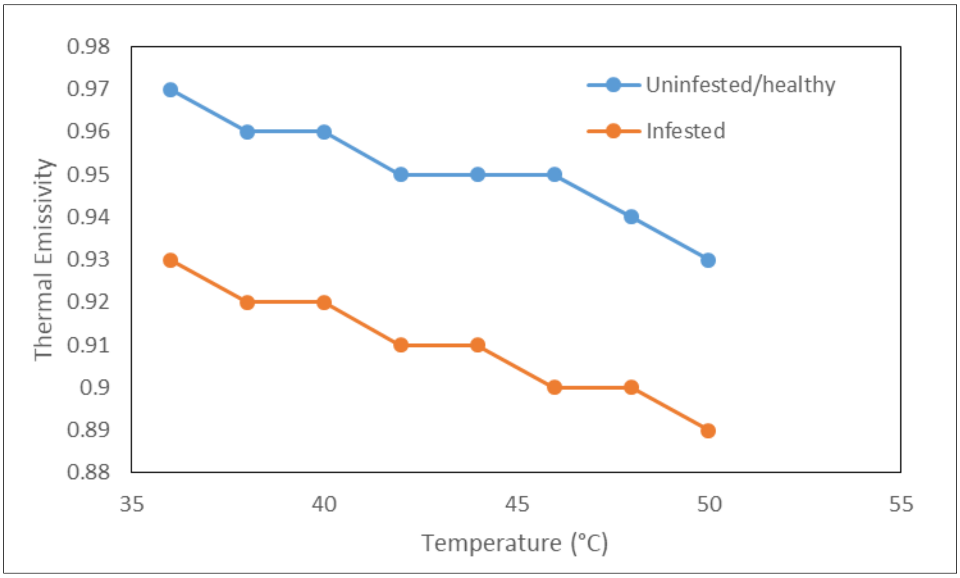


Fig 3: Thermal Emissivity of 'Alphonso' var. mango fruits

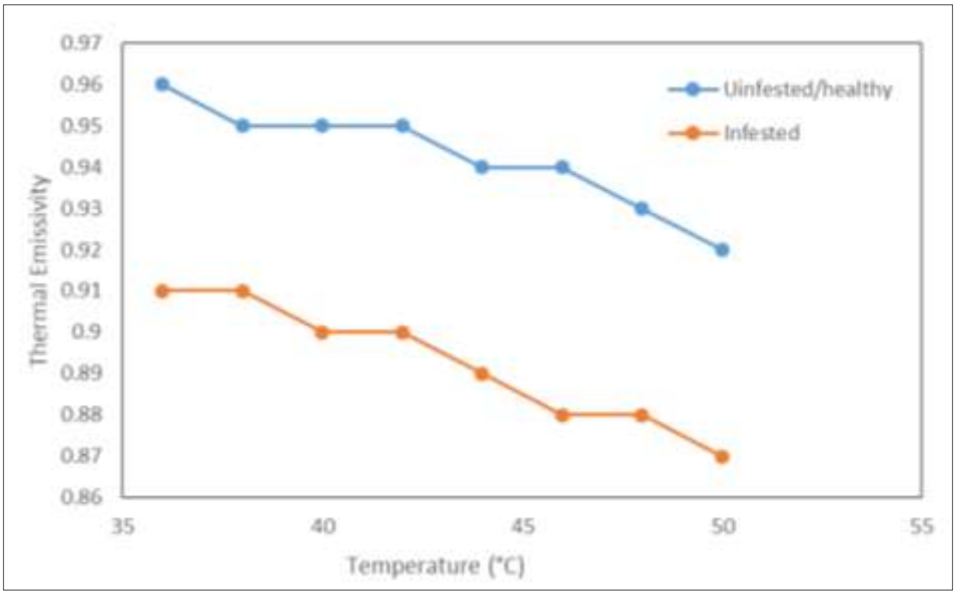


Fig 4: Thermal Emissivity of 'Totapuri' var. mango fruits

Conclusion

The presence of fruitflies in mango affects both its quantity and quality and is therefore considered a pest of quarantine importance in mango export. The engineering properties of foods define the quality of food products. It was observed that thermal emissivity varied for uninfested/healthy and fruit fly infested mango fruits due to differences in surface characteristics of healthy and fruit fly infested mango fruits, attributed to the change in internal structure and composition. It is concluded that the variety and presence of fruit fly influence the thermal emissivity of mango fruits.

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