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# Food Infrared Heating Technology: A Review of Its Impacts on Rice Bran Quality

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***Abstract*** *- Rice bran is a by-product of the rice processing industry that is underutilized. While rice bran contains various nutrients and biological activities, its use as animal feed is limited. It is due to the bran's vulnerability to rancidity. As a result, rice bran will become unfit for human consumption when free fatty acids (FFA) increase to 10%. Stabilization of the lipase enzyme via infrared heating is one technology that it can use to reduce FFA. In addition, controlled infrared heating in terms of temperature, radiation intensity, and exposure time retains nutrients and extends the shelf life of the bran, allowing it to be further utilized as a source of antioxidants, phytosterols, and oleic acid. However, infrared exposure to rice bran can reduce water content and free fatty acids, which affect vitamin E stability, maintain the stability of γ-oryzanol bran during storage, and increases the mortality index of insecticides. These parameters affect the bran's quality during storage. In this review, infrared heating technology in rice bran, beginning with the fundamental principles of infrared, infrared heating sources, and rice bran's physicochemical properties, will be discussed.*

**Keywords —** *Food, infrared, rancidity, rice, transmitter, wavelength*

## I. INTRODUCTION

Rice is the staple food of most Asians. About 90% of the world's rice production and consumption processes are in Asia [1]. It is enormous because the Asian region's size is proportional to the high demand for staple food. The processing of rice consists of grinding and polishing to obtain white and brown rice [2]. In addition, it produces by-products in the form of husk, rice bran, and rice polish during milling [3].

The thin skin that protects the rice and lies below the husks is rice bran. It contains carbohydrates (34-62%), protein (11-15%), dietary fiber (24-29%), lipids (15-22%), minerals (6.6-9.9%), and bioactive compounds such as γ-oryzanol, tocopherol, tocotrienol (Vit. E) and Vit B [4]. Although rice bran has many biological activities and nutrients, its use is restricted to animal feed only. It is because the bran gets rancid quickly. The bran is released from the endosperm when the grinding process occurs—the aleurone protector's high lipid content. Bran's lipase enzyme activity causes triglyceride hydrolysis to become free fatty acids and glycerol [5]. The increase in the concentration of free fatty acids to 10% causes humans to be unable to consume bran [6]. An oxidation reaction will also initiate it. As an antioxidant, vitamin E's bran content plays an active role, causing its availability to decrease. Therefore, need a technological approach capable of preventing and controlling rancidity while preserving nutrition.

Various technological approaches have been implemented to maintain rice bran stabilization. Extraction is one technology that it can use to reduce free fatty acids. This method can reduce the oxidation reaction that occurs, but it is ineffective in its application because it takes a long time. Meanwhile, due to a large amount of milled grain, the processing time in the rice milling process is short [6]. Another step that can it take is lipase enzyme inactivation. It can accomplish it through roasting, dry steam heating, extrusion [7], microwave heating [8], ohmic heating [9], [10], irradiation [11], and infrared heating [5], [12]. Dry steam heating is relatively straightforward, and the technology is cheap. However, the heating process requires a long time and high temperatures, allowing for damage to nutrients [6]. Other technologies, such as ohmic, microwave, and extrusion, also have yield and economic feasibility disadvantages, such as high equipment investment and operating costs [13].

Infrared technology is a potential processing method for grains, particularly bran. It is because foodstuffs directly absorb the heat energy in the infrared. Moreover, heating is more uniform, the time is short, so there are minimal damage and low energy consumption. On the other hand, infrared heating has low investment and operating costs instead of different technologies. Therefore, interesting to examine the benefits and disadvantages of infrared technology in rice bran handling in this review and its effect on these products' quality and nutritional aspects.

## II. INFRARED HEATING TECHNOLOGY

### *A. The infrared heating principle*

The heating uses infrared rays as a source of heat. Infrared light is an electromagnetic wave emitted by atoms or molecules from a material that performs an oscillating motion to produce a specific frequency wave [14], [15]. This frequency is influenced by the transmitter's temperature, which affects the energy radiated on products exposed to infrared light [16]—the greater the frequency, the smaller the wavelength. Infrared has a wavelength of 0.7-1000 mm [17]. Their spectrum ranges can be divided into 1) near-infrared, mid-infrared, and far-infrared, with wavelengths ranging from 0.78 to 1.4 mm, 1.4 to 3.0 mm, and 3.0 to 1000 mm, respectively [18].

The far infrared spectrum is used in food applications. The beam has a wavelength range of 3-30 m. The wavelength of the electromagnetic spectrum has a significant effect on how atoms or molecules react to radiation. For example, in the infrared range of 2.5 to 100 m, an atom or molecule vibrates, generating heat energy. It is due to the Stefan-Boltzmann law, where it asserts that the shorter the electromagnetic wavelength, the faster the temperature rises.

Meanwhile, near-infrared rapidly raises the product's temperature, which can shorten processing time. However, this increases the risk of the product becoming excessively hot, particularly on the surface, resulting in a loss of product quality. Thus, far infrared may be more beneficial. In addition, most food components absorb radiation energy in the far-infrared region and can be used for an extended period. However, if the emitter's operating temperature is too low, it will not generate enough radiation power to reach the thermal process's requirements. As a result, it is essential to choose an infrared emitter with a suitable wavelength and emission strength for food applications.

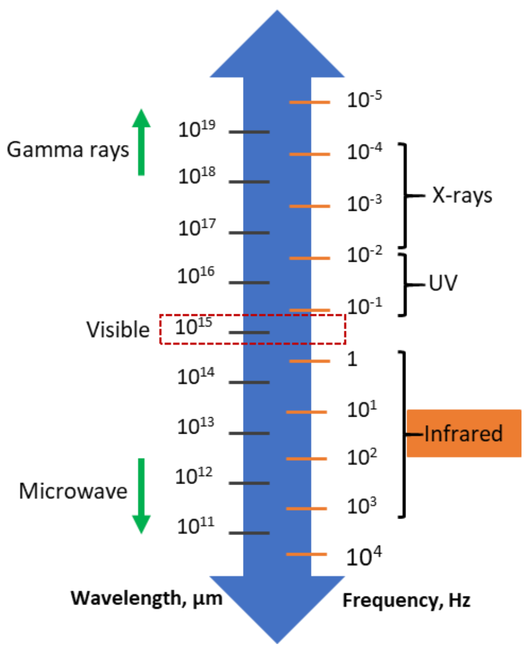


**Fig 1. The spectrum of electromagnetic waves**

Radiation will be emitted by any object above absolute temperature and will become a transmitter. A controlled temperature of the source element, light color, power density, and response time will select the correct transmitter. The transmitter's choice is also based on the type of content of the target food ingredients, such as water, protein, starch, and other organic matter, with varying levels of electromagnetic wave absorption. In the drying, concentrating, and disinfection procedures, different kinds of transmitters and waves are used. Emitters based on a heat source, type of filament, embedded environment, and radiation reflector have also been classified by Das and Das [19].

### *B. Infrared heating source*

When choosing an infrared transmitter for a particular application, the critical parameters in Table 1. are considered. First, the distance factor between the transmitter and the object generates adequate exposure from any infrared system; the distance between the transmitters when indoors. Two types of infrared heat sources generally exist, namely gas and electricity, using infrared lamps. There is more incredible energy and coverage for gas-fired infrared to be used in ground radiation. Meanwhile, electric infrared can be a simple light with a smaller range than gas, often used in the food industry [16], [18].

**Table 1. The characteristics of the transmitters according to their wavelength**

| Parameter | Emitter type with spectrum category | | |
|---|---|---|---|
| | Short | Medium | Long |
| Wavelength | 0,78–1,4 mm | 1,4–3,0 mm | >3,0 mm |
| Radiation color | Bright white | Bright orange | Orange |
| Temperatur | 1300-2600 K | 850-1200 K | 500-800 K |
| Time up to T maximum | A few seconds | One minute | Five minutes |
| Power density | 300 kW/m² | 90 kW/m² | 40 kW/m² |
| Application | Powder coating, adhesive bonding, preheating, pasteurization | Food products drying and curing | Food product drying, baking |
| Souce | Electric | Electric and gas | Electric and gas |

Ref.: Das & Das, [19]

The law of cosine radiation by Lambert states that the maximum radiation on a surface can be observed, which is located at right angles to the source of radiation. Therefore, any deviation from the object's angle to the source (angle q) by the cosine angle q will directly affect the radiation intensity [20]. As a layered reflector, the simplest form consists of an infrared lamp and an aluminum sheet. Giving a reflector will result in additional radiation reflecting the total heat generated by direct radiation plus reflection radiation [21].

For optimal impact, it can adjust the distance between the heat source and the product. Low and high-temperature models can be made to suit a variety of applications with optional convective heating settings. For example, a conveyor oven can be designed like a microwave with a transmitter and reflector and an additional conveyor belt when a continuous system is implemented for large-scale processing [22]. This scheme can be adapted to suit the requirements. In each zone, temperature control is required, and the point reached is achieved by using a reflector, side reflector, and heater (additional if you want to heat more efficiently). The heat from the top, bottom, side, or combinations based on the processed product can be applied in batch and continuous type configurations.

## III. RICE BRAN'S INFRARED PROPERTIES

### *A. Moisture content*

Moisture content is essential for foodstuffs. Its presence triggers metabolic and biochemical reactions [23]). Additionally, the water content will serve as a factor in the growth of microorganisms and destructive insects. Water is essential in controlling the activity of lipase, which can lead to rancidity in rice bran. Yilmaz's [12] reported that bran milled with additional water spray produced high free fatty acids. Low water content causes lipase not to work effectively, and free fatty acid formation is thus hindered.

Infrared waves emit light and act as an irradiator. The waves will be absorbed by the material and converted to heat energy within the material during exposure. In the presence of heat energy, the free water in the food will evaporate and escape. As a result, infrared heating enables a reduction in water content. Wang et al. [6] reported that infrared heating rice and bran at a temperature of 60 $^{o}$C for 55 seconds effectively reduced their water content. The decrease in water content is more effective when combined with the tempering and cooling process. The water content can be reduced by 38.88%- 49.87% from its initial value after 4 hours of tempering. Khir et al. [24] also reported that the decrease in water content in grain is dependent on the duration of exposure and the temperature of infrared heating; the difference in time required to reach the target temperature (60 $^{o}$C) is 60-120 seconds, resulting in a decrease of 2.0-2.1 g water/100g grain. As a result, the amount of water lost during the infrared heating process is dependent on the initial grain moisture content, the duration of the exposure, the intensity of the exposure, and the target temperature.

### *B. Free fatty acids*

Free fatty acids are compounds formed when triglycerides are hydrolyzed by the lipase enzyme found in rice bran. In rice bran, oleic acid is the most abundant fatty acid. Its presence indicates a rancidity-producing oxidation reaction [25], [26]. Free fatty acids have a critical concentration of 10%. These levels are achievable without any preventive treatment in less than seven days of storage [6]. The presence of free fatty acids will continue to rise as the storage time increases. It's because of the continuous metabolic and enzymatic activity during storage [6], [25]. Thus, inhibiting the lipase enzyme is one method of minimizing the oxidation reaction [26].

By inactivating enzymes, infrared heating has been shown to decrease free fatty acids in rice bran. Yilmaz [12] reported that after three months of storage, rice bran exposed to infrared light at 600 W and 700 W for 5.5 minutes and 70 minutes had free fatty acid levels of 6-90%. Three minutes of exposure were insufficient to maintain free fatty acid levels below 10% for three months of storage. It indicates that the inactivation of the enzyme was not optimal due to the exposure time being too short. Additionally, the power of infrared light affects the amount of free fatty acids formed. The more energy consumed, the fewer free fatty acids are formed during storage. Additionally, Yilmaz et al. [13] stated that it should optimize the power settings and exposure time for infrared rays. It is because improper use causes scorching and alters the color and aroma, impairing the organoleptic properties.

Wang et al. [6] reported using infrared light to grain at a power density of 5000 W/m² for 55 seconds, followed by a 4-hour tempering process, to produce rice bran with less than a free fatty acid content of 10% for 38 days of storage. The product does not burn in this state. The combination of infrared tempering technology and a high moisture content results in effective moist heat treatment for lipase inactivation. Lipases' heat resistance is temperature-, time-, and water-dependent. Therefore, water content is a critical factor in enzyme inactivation, as a higher water content results in a lower lipase enzyme's heat resistance [27].

After harvesting, the grain's initial moisture content ranged from 25 to 32 g water/100g dry basis [28]. Based on these conditions, infrared heating can be performed immediately after harvesting, followed by sun-drying to replace the tempering process. As a result, a bran with a longer shelf life will be obtained.

### *C. γ-Oryzanol*

Sterols are naturally occurring compounds found in plants and are frequently referred to as phytosterols. Phytosterols are found in both their natural and esterified forms. Oryzanol is a term that refers to phytosterol esters of the ferulic acid type. Numerous studies have demonstrated that rice bran contains γ-oryzanol, a compound composed of ferulic acid esters of triterpene alcohols and sterols. Rice bran contains oryzanol and possesses beneficial functional properties for human health [29]. The γ-oryzanol has tenfold the antioxidant activity of tocopherol (Vit E), whereas tocotrienol has 40 to 60 times the antioxidant activity of tocopherol [30]. Rice bran's antioxidant activity protects cells from oxidative damage due to oryzanol and vitamin E [31]. Additionally, it has been demonstrated that γ-oryzanol's as a phytosterol function can help lower blood cholesterol and cholesterol levels in the liver [32].

Miller & Engel [33] report that the age of harvest does not affect the amount of γ-oryzanol found in rice bran. Rice harvested prematurely contains between 336 mg/kg γ-oryzanol [13]. This content is lower than rice treated with 269–307 mg/kg infrared light. Irakli et al. [5] reported that grain bran produced from grain exposed to infrared light had 8.31% less oryzanol after four months of storage. Near-infrared and mid-infrared rays are ideal for stabilizing rice bran. It is demonstrated that the use of these rays has little effect on the γ-oryzanol content. These chemicals are plentiful in the aeluron's outer protective layer, which results in a drop in γ-oryzanol throughout the milling process.

### *D. Vitamin E*

Tocopherols and tocotrienols are fat-soluble forms of vitamin E. These vitamins are found in the highest concentrations in bran and rice bran and have antioxidant properties [34]. Furthermore, vitamin E has been shown to inhibit the formation of free radicals in cell membranes, thereby assisting in preventing coronary artery disease [29]. In addition, tocopherols and tocotrienols in rice bran can help prevent the oxidation of lipid compounds, thereby minimizing the formation of free fatty acids. In bran, there are four tocopherol isomers: alpha (α), beta (β), gamma (γ), and delta (δ). The α isomer contains the most significant amount of tocopherol, followed by the gamma isomer.

On the other hand, Tocotrienols exist in only three isomeric forms: α, β, and γ [5]. Therefore, Tocopherol content in rice bran is dependent on the degree of milling. Consequently, the bran produced during the final milling process will contain the highest concentration of tocopherol [12]. According to Irakli et al. [5], infrared heating degrades all types of tocopherols by 20.9%. Tocotrienols, on the other hand, decreased by 11.9%. Tocopherol is the most sensitive type, with a 23% decrease in sensitivity to infrared exposure. By comparison, the type of tocopherol had an 11.5% reduction. The tocotrienol type is the most sensitive, with a decrease of 10.53%. In general, tocotrienol content decreased by 7.5% on average. After a two-month storage period, tocotrienols and tocopherols in bran decreased by 62% and 64%, respectively.

On the other hand, Yilmaz et al. [13] stated that prolonged exposure to low-intensity infrared light results in lower tocopherol than exposure to no infrared light. The highest tocopherol content was obtained using a 1600 W infrared lamp. While using a power source of 500–700 W had no discernible effect on the tocopherol content of bran [13]. The presence of free fatty acids can accelerate the oxidation reaction, causing tocopherols and tocotrienols to deteriorate [5].

### *E. Insecticide*

Insect pests damaged around 27% of milled rice during the storage process [35]. Preventative measures such as the administration of insecticides or pesticides run the risk of hazardous chemical residue accumulation. Pesticide use will result in insect resistance to chemical compounds, making their use less effective [36], [37]. While hot air convection heating provides environmental benefits, its efficiency is significantly lower. The target insect is not killed due to a lack of heat and a lengthy heating time required to reach the desired temperature [38]. Infrared heating technology provides a solution to these issues. This heating is done by delivering waves absorbed into the grain and insects via atomic rotational vibrations, thus increasing both the internal and external temperature. Additionally, it will provide a more effective and safe disinfecting impact [37].

According to Duangkhamchan et al. [39], infrared heating at 60 °C for 2 minutes results in a 100% mortality index for *Sitophilus oryzae* eggs, larvae, and adults. Infrared heating affects the physical characteristics of the rice, too. Infrared-treated rice had more cracks and a lower level of hardness than untreated rice.

Pei et al. [37] examined the effect of infrared irradiation on *Sitophilus zeamais* and *Tribolium castaneum*. A mortality index of 100% was achieved in the *Sitophilus zeamais* species when exposed to 2125 W/m² infrared light at a temperature of 65 °C, while it reached 96% at 55 °C. With a target temperature of 50 °C, infrared powers of 2125, 2780, and 3358 W/m² were unable to achieve a 100% *Sitophilus zeamais* mortality index. However, when it gave additional treatment in 4 hours of tempering, the mortality index increased.

Meanwhile, because *Tribolium castaneum* is more resistant to heat and vibration than *Sitophilus zeamais*, its mortality index is lower. However, even at a target temperature of 65°C and a power density of 2125-3358 W/m², it produces a 100% mortality index. These findings indicate that the target temperature is positively correlated with the pest mortality index when the heating rate and radiation strength are varied. Table 2 provides a result study on the effect of infrared exposure on rice bran's physicochemical parameters.

**Table 2. Characteristics of rice bran exposed to infrared radiation**

| Purpose | Process conditions | Findings | Ref. |
|---|---|---|---|
| Reduced water content | Infrared intensity= 5348 W/m² ; t= 15, 30, 40, 60, 90, and 120 s; T= 35 °C | • Water diffuses in the briefest exposure time<br>• The rate at which water evaporates is positively correlated with temperature | [40] |
| Stabilization | Exposure to near and mid-infrared rays | • There was no significant difference in the characteristics of the bran produced when exposed to near-infrared or mid-infrared | [41] |

| Purpose | Process conditions | Findings | Ref. |
|---|---|---|---|
| | | • Due to infrared exposure, it lost as much as 50% of the tocopherol content<br>• The levels of -oryzanol and free fatty acids remain unchanged | |
| Stabilization | Infrared power= 500, 600, 700 W<br>t= 3, 5.5, 7 min. | • Scorching occurs when infrared light is exposed at 700 W for ten minutes.<br>• There is no discernible effect on the content of water or protein in the body.<br>• After three months of storage, infrared 600-700 W increases free fatty acid levels by 10%.<br>• Tocopherol levels increased as a function of exposure time, infrared intensity, and milling stage. | [42] |
| Stabilization | Infrared intensity= 5000 W/m²;<br>T= 60 °C;<br>t=55 s + tempering 1-4 hours | • Water content decreased significantly, which was related to the initial moisture content and the duration of tempering<br>• The number of broken rice grains is increasing<br>• The length of tempering time and initial moisture content both contribute to an increase in shelf life synergistically | [43] |
| Stabilization | Infrared power= 800-2200 W; comparison of near- and mid-infrared exposure on young grain | • Increased infrared power reduces free fatty acids significantly<br>• The power and exposure time used to calculate the results affect their significance | [44] |
| | | • γ-Oryzanol and tocopherols are unaffected by infrared heating | |
| Disinfestation | Infrared intensity= 5348 W/m² | • Infrared exposure for 60-90 seconds kills almost all *R. Dominica* in all stages of growth<br>• An additional tempering treatment on infrared exposure for 60-90 seconds resulted in a nearly 100% mortality index | [45] |
| Disinfestation | Infrared:<br>T= 50, 55, and 60 °C | Infrared exposure for 2 minutes at a temperature of 50-60 °C resulted in a 100% mortality index in *S. oryzae* | |
| Disinfestation | Infrared intensities= 2125, 3358, and 3974 W/m²;<br>T= 50, 55, 60, and 65 °C | Infrared 2780 W/m² at 60 °C produced a % mortality index in S. *zeamais* and *T. castaneum* while having no adverse effect on rice quality | |
| Disinfestation | Infrared intensities= 2.15, 2.83, 10.84 kW/m²;<br>T= 60°C | At 10.84 kW/m², infrared kills more larvae and adults than traditional dehumidification. Meanwhile, there was no discernible difference between the intensities of 2.15 and 2.83 kW/m² | |

## IV. CONCLUSION

Infrared heating of unhulled rice is a preventive and solution step in dealing with problems during the milling and storage of rice and bran. Rice bran is high in nutrients but easily damaged. As a result, it is critical to preserve its quality for future use. Rice bran has a high-water content, free fatty acids, vitamin E, and ɣ-oryzanol content. Furthermore, infrared heating affects the water content of rice, reducing its shelf life.

Additionally, infrared exposure produced an insecticidal effect. However, it is necessary to monitor the target temperature, the infrared intensity, and the exposure time. It is intended to ensure that rice and bran's physicochemical and organoleptic properties are not compromised.

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