# DETERMINING RADIO FREQUENCY HEATING UNIFORMITY OF MIXED BEANS DURING DISINFESTATION TREATMENTS

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*Since chickpeas and lentils are difficulty to artificially infest with live insects for radio frequency (RF) treatment validation, black-eyed peas and mung beans were selected to infest with insects before mixing with chickpeas and lentils. Temperature difference between black-eyed pea and chickpea or between mung bean and lentil were determined in a pilot-scale 27 MHz RF unit. When subjected to RF heating for 6 and 10 min, the final temperatures in black-eyed pea at the moisture content of 8.8% and mung bean at 10.2% w.b. were 6 and 4°C higher than those in chickpea at 7.0% and lentil at 7.1% w.b. when the sample temperature was raised to 60°C. To obtain conservative results, chickpea and lentil should reach slightly higher temperatures than the black-eyed pea and mung bean in the same treatment. By reducing the moisture contents in black-eyed pea and mung bean to 2.6% and 3.7%, respectively, their final temperatures were about 3.5 and 3.7°C lower than those of chickpea and lentil.*

**Keywords:** Infestation, Legume, Dielectric properties, Moisture, RF

## INTRODUCTION

Natural field infestation of cowpea weevil (*Callosobruchus maculatus*) in chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*) has forced the US legume industry to meet postharvest phytosanitary regulations before exported to India, Korea, Spain, and Latin American countries (USADPLC, 2007). The current most common method for postharvest insect control in legumes relies on fumigation with methyl bromide (MeBr) (Carpenter et al., 2000). However, because MeBr depletes the stratospheric ozone layer, the amount of MeBr produced and imported in the US is being incrementally reduced (Browner, 1999; UNEP, 2006). Radio frequency (RF) heating holds potential as an alternative method for insect control in legumes. Many studies have explored the use of RF energy in control of insects in agricultural commodities (Nelson and Payne, 1982; Nelson, 1996; Tang et al., 2000; Marra et al., 2009). Lagunas-Solar et al. (2007) reported RF control of insects in rough rice with acceptable quality. Wang et al. (2001, 2002) and Mitcham et al. (2004) developed pilot scale RF treatments for control of codling moth and navel orangeworm in in-shell walnuts. Wang et al. (2007a, b) further scaled-up the treatments on industrial-scale conveyorized RF systems for in-shell walnuts with acceptable product quality and validated the treatments using fifth-instar navel orangeworms. Recently, Wang et al. (2010) developed postharvest disinfestations treatments for legumes using RF energy. It is necessary to validate the RF treatment protocol with efficacy tests. Although cowpea weevil has been associated with both chickpeas and lentils (Arbogast, 1991), Ahmed et al. (1989) showed that some varieties of chickpeas are very poor hosts for cowpea weevil, and Islam (2007) reported that lentils were not preferred by ovipositing females. Our preliminary observations showed that the cowpea weevil isolate, which is reared on black-eyed pea (*Vigna unguiculata*), produced very few eggs on available chickpea and lentil varieties. However, we found cowpea weevil oviposition and development on mung bean (*Vigna radiata*), a bean known to support cowpea weevil development (Arbogast, 1991), to be similar to that on black-eyed peas. Because of the poor oviposition on chickpeas and lentils, we selected black-eyed peas and mung beans, similar in size to chickpeas and lentils, respectively, as surrogate hosts in validation tests. Infested surrogate hosts will be placed within chickpeas and lentils during RF treatments. To obtain conservative results, chickpeas and lentils should reach slightly higher temperatures than infested black-eyed peas and mung beans. Final temperatures in mixed beans depend on their thermal and dielectric

properties under the same RF fields (Nelson, 1996; Wang et al., 2003a). Because the loss factor of legumes increases with increasing moisture content (Guo et al., 2008, 2010), it is possible to adjust the RF heating rates in samples by controlling the sample moisture contents.
The objectives of this study were: (1) to measure the properties of legumes; (2) to compare the temperature-time history and final temperatures of legumes when subjected to 27 MHz RF heating; and (3) to determine the moisture contents needed to produce heating rates in black-eyed pea and mung bean that are slightly lower than chickpea and lentil.

## MATERIALS AND METHODS

### *Density and specific heat measurement*

Chickpea and lentils were purchased from George Brocke & Sons, Inc., Kendrick, ID, USA; black-eyed peas from Pacific Grain & Foods, Fresno, CA, USA; and mung beans from Living Whole Foods, Inc., Springville, UT, USA. The initial moisture contents of chickpea, lentil, black-eyed pea, and mung bean were 7.0%, 7.1%, 8.8%, and 10.2% w.b., respectively.
The bulk densities of black-eyed pea and mung bean at room temperature were measured by a standard volume method using a 25.5 cm×15 cm×10 cm container (Fig. 1). For each legume, the container was fully filled with product and then weighed. From weight and volume of the sample, mean and standard deviation values of bulk density were estimated over three replicates.

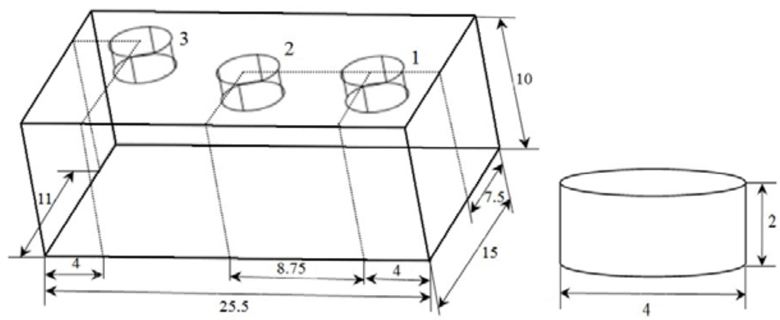


**Fig. 1. Experimental plastic treatment container with location of three cups for sample temperature measurements (all dimensions are in cm)**

The true density of black-eyed pea and mung bean were measured using the liquid displacement method. To avoid water absorption in legumes during measurement, toluene ($C_6H_5CH_3$) was used as a displacement liquid because it shows little tendency to permeate through the sample and has stable specific gravity and viscosity (Guo et al., 2010). The true density was determined by dividing the weight of randomly selected 10 g samples by the volume occupied by the samples as measured with toluene in 50 ml pycnometers. The measurements were replicated three times.
The specific heat of black-eyed pea, chickpea, mung bean, and lentil were measured with a differential scanning calorimeter (Q2000, TA Instruments, New Castle, DE, USA). The legumes were cut into small pieces, and samples of about 10 g were put into the small aluminum pan (30 µL) and then the pan was sealed before measurements in the differential scanning calorimeter. The samples were heated at a rate of 10°C/min and a temperature range of 20-90°C was selected.

### *Dielectric properties measurement*

The dielectric properties of mung bean and black-eyed pea samples were measured by an open-ended coaxial-line probe connected to an impedance analyzer (HP4291B, Hewlett Packard Corp., Santa Clara, CA, USA). After following the standard calibration procedure, the dielectric properties were determined over frequencies of 10-1800 MHz, temperatures of 20-90°C and four moisture levels. The detailed information about the dielectric property measurement system and procedure can be found elsewhere (Wang et al., 2003b; Guo et al., 2008). The measurements were replicated two times.
Since the irregularly shaped legume samples do not make good contact with the flat probe surface for accurate measurements, compressed pellets made of homogeneous legume flour samples were used in the measurement. The flour was prepared from legume seeds by grinding in a coffee grinder, and the pellets were compressed in a mold using hydraulic press (Fred S. Carver Inc. Summit, NJ, USA). Because dielectric properties of particulate materials are affected by sample density (Berbert et al., 2002), the true density of each legume was used as the criterion for compressing the flour samples as described by Guo et al. (2008).

The moisture contents of legume flours were determined by the vacuum oven drying method. About 2-3 g flour samples were placed in aluminum dishes and then dried in a vacuum oven (ADP-31, Yamato Scientific America Inc., Santa Clara, CA, USA) at 130°C and 75-85 kPa for 1 h (AOAC, 2002). Three samples were placed in desiccators with CaSO4 to bring sample to room temperature before weighing.

***RF heating systems***

A 6 kW, 27 MHz pilot–scale RF system (COMBI 6–S, Strayfield International, Wokingham, U. K.) was used to determine the heating rates and uniformity in the mixed beans. A detailed description of the RF system can be found in Wang et al. (2010). In the current study, legume samples in a plastic container (Fig. 1) were placed on the center of the bottom plate electrode without hot air or moving conveyor belt. The electrode gap was fixed at 13.3 cm to achieve an appropriate heating rate (Wang et al., 2010).

We compared the heating rates under RF of target legumes with their surrogates (chickpea with black-eyed pea or lentil with mung bean) as follows. Three small cylindrical plastic cups (4 cm diam × 2 cm deep) filled with legumes (16-19 g) were buried in a larger test container (25.5 cm × 15 cm × 10 cm) also filled with legumes (3 kg). The cups were buried at three representative locations (Fig. 1) so that the legume surface within the cup was leveled with that of the larger container. Four tests were done; 1) both the larger container and the cups were filled with chickpeas, 2) both the larger container and the cups were filled with lentils, 3) the larger container was filled with chickpeas and the cups were filled with black eyed peas, and 4) the larger container was filled with lentils and the cups were filled with mung beans.

The container was subjected to RF heating from room temperature (23°C) until the sample temperature reached about 60°C. The temperatures of the beans were measured by two FISO optic sensors (UMI, FISO Technologies Inc., Saint-Foy, Quebec, Canada) during RF heating. One was placed in the center of the middle cup (Cup #2) and another one was located near the external wall of Cup #2.

## RESULTS AND DISCUSSION

***Density and specific heat of legumes***

The bulk density and true density of black-eyed pea and mung bean at their initial moisture contents were shown in Table 1. Mung bean had the higher bulk density and true density than black-eyed pea. The specific heat of the four tested legumes as a function of temperature is shown in Fig. 2. For all four legumes, the specific heat increased with increasing temperature in the range of 20-90°C. This trend is similar to that found for corn and rice as reported by Valdez-Fragoso et al. (2001).

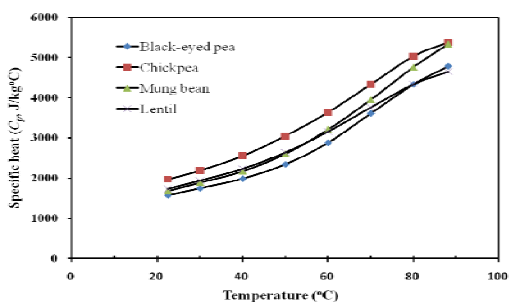


**Fig. 2. Specific heat of four types of legumes as a function of temperature**

**Table 1. Bulk density and true density of black-eyed pea and mung bean at their original moisture content and ambient temperature (25°C)**

| Legumes | Moisture content (w.b.) | Bulk density (kg/m$^3$) | True density (kg/m$^3$) |
|---|---|---|---|
| Black-eyed pea | 8.8% | 690±3 | 1133±15 |
| Mung bean | 10.2% | 920±6 | 1455±3 |

***Dielectric properties***

Dielectric properties of black-eyed pea and mung bean as a function of moisture content and temperature are shown in Fig. 3. The dielectric properties of black-eyed pea increased with temperature and moisture content (Fig. 3a), which was also observed for chickpea (Guo et al., 2008). By comparison, the dielectric constant of black-eyed pea was close to that of chickpea when the temperature was below 60°C for all four moisture content levels, but the loss factor of chickpea was higher than that of black-eyed pea, especially at the high moisture content and temperature levels. Dielectric properties of mung beans are shown in Fig. 3b. The same increasing dielectric properties with temperature and moisture content were found for both mung beans (Fig. 3b) and lentil (Guo et al., 2010). Both dielectric constant and loss factor of mung bean were similar to those of lentil when the temperature was below 60°C at each moisture content level.

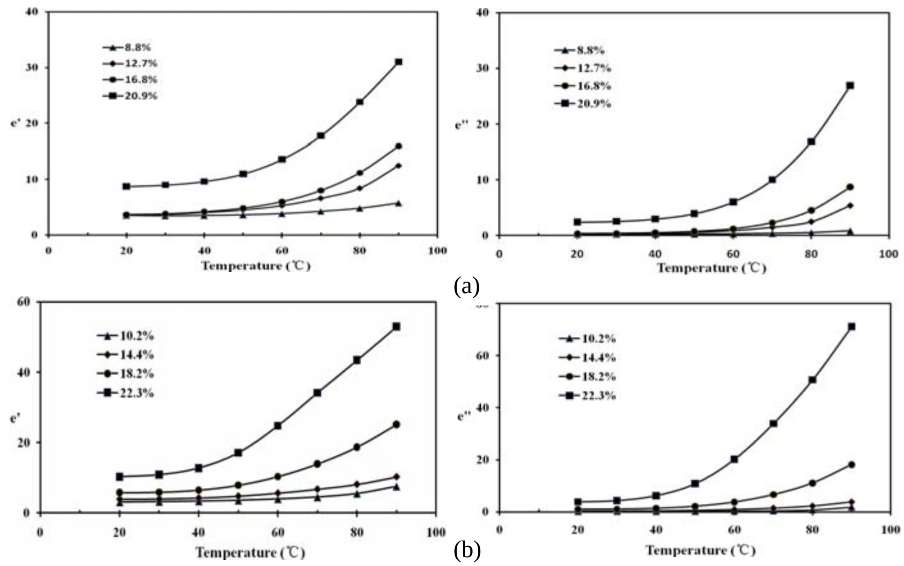


**Fig. 3. Dielectric properties of black-eyed peas (a) and mung bean (b) at 27 MHz as a function of moisture contents and temperatures**

***RF heating rates and uniformity***

Fig. 5 shows the temperature-time histories during RF heating of chickpeas when Cup #2 was filled with chickpeas and black-eyed peas. The temperature-time history in the center of Cup #2 when filled with chickpea was almost the same as that outside the cup (Fig. 5a), suggesting that the temperature difference caused by the three small cups was negligible. When the cups were filled with black-eyed pea, there was relatively large temperature difference between the center of Cup #2 and the outside of the cup (Fig. 5b). The heating rate in black-eyed pea was higher than that of chickpea under the same RF processing conditions and their final temperature difference was about 6.5°C. The different heating rates between black-eyed pea and chickpea were probably caused by the difference of dielectric loss factor, density and specific heat.

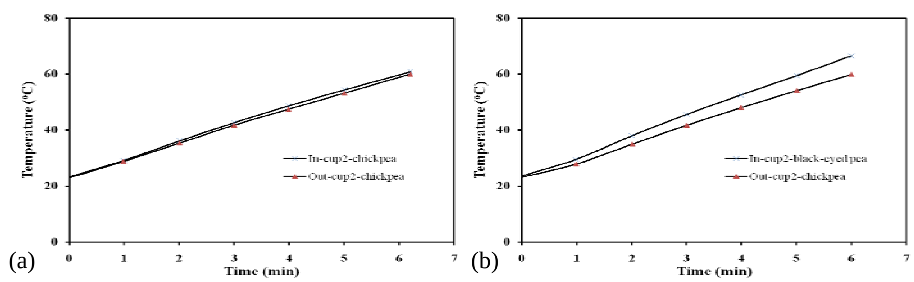


**Fig. 5. Temperature-time histories during RF heating under an electrode gap of 13.3 cm for chickpeas inside and outside Cup #2 when filled with chickpeas (a) and black-eyed peas (b)**

Fig. 6 presents the temperature-time histories during RF treatments for lentil and mung bean. When both the large container and the cups were filled with lentils, the temperature-time history in the center of Cup #2 was close to that outside the cup (Fig. 6a). When the cups were filled with mung beans, the heating rate in the center of Cup #2 was higher than that outside the cup under the same RF processing conditions (Fig. 6b). The final temperature in mung bean was about 4.4°C higher than those in lentil after RF heating for 10 min. This temperature difference could also be explained by the difference of the dielectric loss factor, density and specific heat.

Since the experimental results showed that the heating rate of the proposed surrogates black-eyed pea (8.8% w.b.) and mung bean (10.2% w.b.) was higher than the target products chickpea (7.0% w.b.) and lentil (7.1% w.b.), it was necessary to reduce the RF power absorption of the surrogates by reducing their moisture content. Fig. 7 shows the temperature-time histories of black-eyed pea and mung bean with reduced moisture contents (2.6% w.b and 3.7% w.b., respectively) in Cup #2 as compared to that outside the cup. The final temperature in black-eyed pea was about 3.5°C lower than those in chickpea at the same treatment conditions when the temperature of the black-eyed pea samples was raised to 60°C, and the final temperature in mung bean was about 3.7°C lower than those in lentil (Fig. 7). These results show that moisture content can be used to adjust the heating rates of legumes during RF treatments.

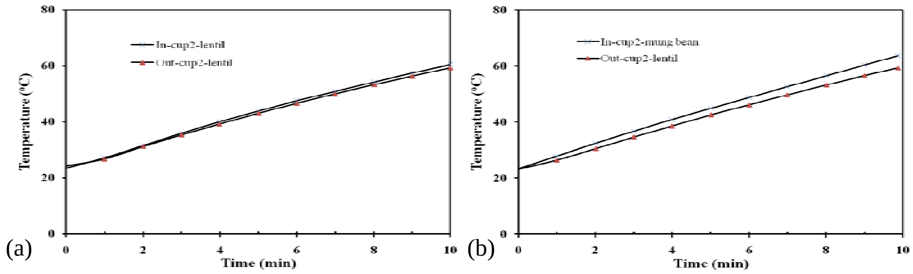


**Fig. 6. Temperature-time histories during RF heating under an electrode gap of 13.3 cm for lentils inside and outside Cup #2 when filled with lentils (a) and mung beans (b)**

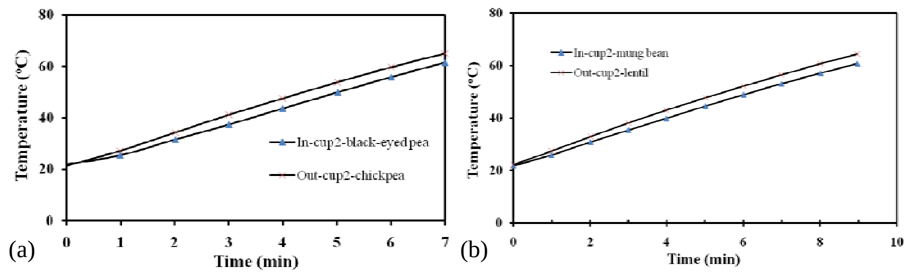


**Fig. 7. Temperature-time histories during RF heating under the electrode gap of 13.3 cm for the target legumes inside and outside Cup #2 when filled with chickpeas in the container and black-eyed peas at the reduced moisture content of 2.6% w.b. in the cups (a) and lentils in the container and mung beans at the reduced moisture content of 3.7% w.b. in the cups (b)**

## CONCLUSIONS

To validate proposed RF treatment protocols for cowpea weevil control in legumes, black-eyed pea and mung bean were selected as surrogate legumes with high laboratory infestation rates to mix with target legumes (chickpea and lentil) with low infestation rates. To obtain conservative results, target lentils and chickpeas should reach slightly higher temperatures than infested mung bean and black-eyed pea in the same RF treatment. The final temperatures in black-eyed pea and mung bean were 6 and 4°C higher than those in chickpea and lentil at the same RF treatment conditions when the temperature of the samples was raised to 60°C at initial moisture contents. By reducing the moisture contents in black-eyed pea and mung bean to 2.6% and 3.7%, the heating rates during RF heating were lowered to below those of chickpea and lentil, suggesting that conservative results from subsequent insect mortality and product quality studies should be obtainable.

## ACKNOWLEDGMENTS


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