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Effect of Infrared Treatment on the Disinfestation of Black Gram Seeds (Vigna mungo) on Storage

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Abstract
Effect of infrared (IR) treatment on disinfestation of black gram seeds was studied during storage. Untempered and tempered (15% moisture) seeds were IR treated at 150, 250, 350 and 450^{0}C, packed in polypropylene pouches (PP), stored at ambient conditions (15-35^{0}C) to check infestation periodically. During storage, seed weight and bulk density decreased significantly ($p \leq 0.05$) with the significant increase ($p \leq 0.05$) in uric acid contents in control and IR treated seeds at 150 and 250^{0}C. Based on the uric acid level, control as well as IR treated seeds at 150^{0}C became unfit for consumption after 3 months of storage and the seeds treated at 250^{0}C after 6 months. Uric acid content remained almost unchanged in the samples treated at 350 and 450^{0}C throughout the storage period. In untempered samples, IR treatment affected germination and rheology at 350^{0}C, while in tempered ones germination was affected at all the temperatures of IR treatment with less rheological changes.
Keywords: Black gram, infrared, disinfestation, physico- chemical properties, rheology, germination, storage.

1. Introduction

Pulses are dried edible portions of legume plant and known as poor man's meat as it constitutes a rich sources of proteins, vitamins and minerals for most of the vegetarian population of the country (Singh and Singh 1992). Black gram (*Vigna mungo*) is an important seasonally produced pulse crop (Pande and Mishra 2013)in India. India is the largest producer and consumer of black gram in the world (Kavitha et al., 2013). Proper post harvest management for the storage of grains through out the year is of utmost importance as they suffer a great damage due to the growth of insect pests and microorganisms (Akhtari et al., 1993). The spoilage causing microorganism and insect pests are also involved in contaminating the food products with their fragments, webbings and faeces thereby affecting the over all quality of pulses (Zain and Baker 1992). The damage caused due to the insect infestation of pulses were eventually estimated to be 10-40% (Upadhyay and Ahmed 2011). Pulses are known to be infested severely by the beetles of the family Bruchidae (Coleoptcea) popularly known as pulse beetles or bruchids (Hill 1990, Pande and Mishra 2013). One of the popularly used methods for the post harvest disinfestation is the fumigation. However, due to development of resistance by the insects to the most commonly used chemicals, environmental concerns and the hazardous residual effects of these chemicals on human health, have now opened the gate for possible exploration of non chemical alternatives (Vadivambal et al., 2010, Abo-el-Saad et al., 2011) for the disinfestation of grains. One such environmental friendly disinfestation treatment of pulses is the temperature treatment for a short period of time with a minimum impact on product quality and environment. Several thermal treatment methods such as hot air treatment, radio frequency energy and microwave disinfestation have been employed extensively for disinfestation (Fields 1962, Dowdy 1999, Dosland et al., 2006, Wang et al., 2010, Dronachari and Yadav, 2015) of pulses.

IR radiation is one such heat treatment that is extensively used in the food industry for various stages of food processing applications (Krishnamurthy et al., 2008). IR represents the electromagnetic radiation works with a wavelength ranging from 0.7 to 1000 µm and has several advantages such as shorter cooking time, uniform heating of the products, reduced quality loss, simple and versatile method (Rastogi, 2012) as compared to the conventional methods of heating. IR disinfestation is a heat treatment which is relatively easy to use at a faster rate leaving no chemical residues. The present study is, therefore, focused on the application of infrared radiation treatment for the control of infestation of black gram seeds during storage without causing a deleterious effect on product quality.

2.0 Materials and methods

2.1 IR treatment of black gram seeds

The IR treatments were carried out on both tempered and untempered black gram seeds. One lot of black gram seeds containing 2 kg samples each was exposed to different IR temperatures viz 150, 250, 350, and 450^{0}C for 50-55 sec. After exposure to IR, seed temperature was found to be 32±1^0 at 150^{0}C, 50±1^0 at 250^{0}C, 69±2^0 at 350^{0}C and 84±1^0 at 450^{0}C. Samples were cooled and packed in poly propylene pouches (PP, 75µ), stored at ambient conditions (15-35^{0}C) to check infestation periodically during storage. A representative sample without IR treatment was referred as control.

Another lot of black gram seeds was tempered to 15% moisture. Initially the moisture content present in

black gram seeds was determined. The amount of moisture required to be added to enhance the moisture content of the seeds to 15% was calculated. Then the tempering process was carried out by periodically sprinkling the pre calculated amount of water to the seeds by placing it in PP pouches and tumbling it after every addition to ensure even distribution of water to the seeds. After the completion of tempering process, the seeds were allowed to attain equilibrium by keeping it as such in PP pouches at room temperature for 5-6 hr and then IR treated and packed as mentioned above.
In this case also, the seeds without IR treatment were considered as the control sample.

2.2 Preparation of black gram flour
Untempered and tempered control black gram seeds along with their IR treated ones at different temperatures were ground finely to pass through 100 mm mesh sieve and used for experimental studies.

2.3 Physico chemical properties
IR treated untempered and tempered black gram seeds along with their respective control samples were studied for the 1000 kernel weight by randomly selecting and weighing 1000 kernels from a well mixed sample (Kavitha et al., 2013).

Water/oil absorption capacity of control and IR treated black gram seeds was performed as per Beuchat (1977), Eke & Akobundu (1993) methods. Bulk density was estimated as per Narayana & Narasingha (1984). Uric acid was extracted as per AOAC (1980) methods and estimated as per the method of Oser (1971).

2.4 RVA analysis
Pasting properties of flours were measured using a Rapid Visco-Analyser 4D (Newport Scientific Pvt Ltd, Warie Wood, Australia) according to Yadav et al., (2008). The test proceeded and terminated automatically. Heating of the slurry in the equipment was done under a constant rate of shear and the increase in viscosity of a material was measured as torque on the spindle and a curve was traced. Flour sample (3.5 g on 14% moisture basis) was dispersed in 25 ml distilled water. The rotating speed of paddle was 160 rev/ min except for first 10 sec (960 rev/ min) with the suspension equilibrating at 50^{o}C for 1 min and heated at the rate of 12^{o}C/ min to 95^{o}C and then held at 95^{o}C for 2.5 min. The sample was then cooled to 50^{o}C at the rate of 12^{o}C/ min and then held for 3 min at 50^{o} C. Breakdown viscosity, set back viscosity, pasting temperature, etc. were recorded in terms of Rapid Viscosity Units (RVU).

2.5 Germination
Germination of both untempered and tempered black gram seeds subjected to different IR temperatures along with their respective control samples was carried out by soaking 100 seeds in tap water for 10 hr at room temperature. The water was drained and the seeds were spread on petri plates covered with muslin cloth and germinated at room temperature up to 48 hr. The number of germinated seeds were counted and calculated as germination percentage.

2.6 Statistical analysis
All the reported values are the mean of three replicates each and statistical analysis was carried out by using statistical software (Statistica, Ver 7.1 Series 1205). Experimental results were subjected to three way analysis of variance for significance ($p \leq 0.05$) using Duncan's multiple range tests (Snedecor and Cochran 1968).

3.0 Results and discussion
3.1 Changes in rheological characteristics
The pasting properties of flours of untempered and tempered black gram seeds treated at various temperatures of IR along with their control samples are represented in Table 1. Flours of tempered seeds have shown slightly higher values for break down, final, set back viscosities and pasting temperature as compared to untempered ones. Breakdown, set back, final viscosities and pasting temperature of control untempered and tempered blackgram seeds were 30.49 & 34.02, 80.23 & 82.45, 20.94 & 21.32 and 82.11 & 82.90 RVU respectively. Between various temperatures of IR treatment in both untempered and tempered seeds, these parameters decreased slightly but significantly ($p \leq 0.05$). But IR treatment at 450^{0}C has a detrimental effect on the rheology of the seeds. At 450^{0}C, seeds have shown 20.11 & 27.45, 69.12 & 74.32, 12.15 & 16.44 and 80.02 & 81.01 RVU of break down, final, set back viscosities and pasting temperature in untempered and tempered seeds respectively, significantly lesser ($p \leq 0.05$) than the their control samples. The changes in the pasting properties of both untempered and tempered seeds of black gram indicated that the quality of the starch has been altered to some extent at varying temperatures of IR treatment. Xie et al., (2013) also observed the changes in the visco elastic behavior of the potato starch leading to leaching and fracture of starch granules when microwave treated at different intervals of time from 0 to 20 sec thus contributing to the rheological changes.

3.2 Changes in germination capacity

The results of the germination study conducted in control as well as IR treated untempered and tempered black gram seeds at various temperatures are represented in the Figure 1. Untempered control seeds have shown 87.3% germination and IR treatment up to 350^0C has not affected the germination capacity of the seeds, found similar to control ones. However IR treatment of the seeds at 450^0C decreased its germination capacity significantly (p≤0.05) from 87.3 to 46.2% as temperature is one of the factors that influences germination (Silveira and Overbeck 2013). Shoughy and Elzen (2014) also reported significant decrease in the germination percent in cowpea and faba bean at various power level of exposure to microwave radiations. The control tempered seeds of black gram having 15 % moisture showed germination capacity of around 85% which decreased significantly (p≤0.05) at each stage of IR treatment. Germination capacity decreased to 70.40, 50.11, 30.40 and 18.20% during IR treatment of the seeds at 150, 250, 350, 450^0C respectively. The higher reduction in germination capacity of tempered seeds than that of untempered ones may be due to the higher moisture content which facilitated more penetration of heat inside the grain that destroyed the quality of the seeds.

3.3 Changes in moisture content

The initial moisture contents of untempered and tempered control seeds was 10.75 and 15.21% respectively (Table 2). On exposure to IR radiations at different temperatures, there was a significant loss (p≤0.05) in moisture content of seeds and was found to be 17.02% in untempered seeds and 20.38% in tempered seeds. As the storage period increased, there was a significant increase (p≤0.05) in the moisture content of tempered and untempered seeds as well as their respective control samples. The increased insect population has produced more moisture content in the seeds as a result of their metabolic activity (Modgil, 2003) and also the barrier property of the packaging material contributed to the significant increase in the moisture. The moisture content increased from 10.50 to 12.99%, 9.82 to 12.24%, 9.49 to 11.23% and 8.92 to 10.26% in untempered samples and 14.72 to 17.02%, 13.88 to 16.25%, 13.02 to 14.76% and 12.11 to 13.97% in tempered samples treated at 150, 250, 350, 450^0C respectively during 12 months of storage. Even though, tempered seeds treated at 350 and 450^0C have contributed significant amount of moisture to the seeds at the end of the storage period, the samples were found infestation free, may be the high temperature treatment has destroyed the insect larvae which inhibited further infestation in seeds.

3.4 Changes in 1000 kernel weight

Initially, IR treatment at different temperatures significantly (p≤0.05) reduced the seed weight (Table 3) particularly in tempered samples due to the decrease in their moisture contents due to heat treatment (Table 2). As the storage period progressed up to 12 months, there was a significant reduction (p≤0.05) in the 1000 kernel weights of control as well as seeds treated at 150 and 250^0C. After 3 months of storage, in control as well as IR treated samples at 150 and 250^0C (both untempered and tempered), the loss of weight was observed significantly (p≤0.05) more as there was a visible infestation in them and insects have started emerging out after consuming the endosperm part of the kernel. The control untempered and tempered seeds have shown 46.24 and 44.45% reduction in thousand kernel weights and the same treated at 150 and 250^0C have shown 41.00, 31.26 and 42.62, 30.79% reduction respectively after 12 months of storage. Modgil (2003) also reported a decrease in the seed weight of the green gram due to insect infestation. Both in untempered and tempered IR treated samples at 350 and 450^0C, the seed weight remained almost constant indicating no damage and found completely infestation free during the entire storage period.

3.5 Changes in bulk density

The bulk density of untempered and tempered control black gram seeds as well as their IR treated samples at various temperatures are indicated in the Table 4. Initially IR treatment of both untempered and tempered seeds at different temperatures caused a significant decrease (p≤0.05) in bulk density after 350^0C. But during first 3 months of storage, there was no significant difference (p≥0.05) in bulk density between control as well as IR treated seeds at 150 and 250^0 C. But after 3 months of storage in the same samples, bulk density decreased significantly (p≤0.05) as the adult insects emerging out of the seeds have created holes making the grain more porous after consuming its endosperm portion. Similar results were reported by Vimala and Pushpamma (1983), Modgil and Mehta (1994) for the decrease in bulk density of grains due to insect infestation. Eventhough samples treated at 250^0C has shown a significant decrease (p≤0.05) in bulk density after 3 months of storage, but visible infestation was noticed only after 6 months, While in IR treated samples at 350 and 450^0 C slight changes in the bulk densities were observed during the entire storage period.

3.6 Changes in water and oil absorption capacity

The water and oil absorption capacities of untempered and tempered seeds of black gram along with the untreated control samples during 12 months of storage are reported in Tables 5 & 6. It is clear from the tables that, various temperatures of IR treatment has caused slight but significant increase ($p \leq 0.05$) in water and oil absorption capacities of both untempered and tempered seeds. Water absorption capacity increased from 2.29 to 2.50 g/g in untempered seeds and 2.42 to 2.74 g/g in tempered seeds (Table 5). The dissociation of protein that occurred during the heating having more water binding sites could be attributed to the increase in water absorption capacity (Rehman and Mustafa 1988) .The oil absorption capacity of the seeds also increased due to IR treatment. In untempered and tempered seeds, it increased from 1.15 to 1.42 g/g and 1.32 to 1.50 g/g respectively (Table 6). The increase in oil absorption capacity may be due to the denaturation of proteins by heat which opened non polar hydrophobic chain residues from interior protein molecule (Abbey and Ibeh 1987). Zain & Ooi (1994) also reported the increase in water and oil absorption capacities in rice, peanut and mung bean seeds during microwave treatment for different time intervals. Blanching of cocoyam flour corn for 5 and 15 min in boiling water also showed significant increase in water and oil absorption capacities (Obeigbuna et al., 2014). On storage also, infestation has caused a significant increase ($p \leq 0.05$) in both water and oil absorption capacities of control untempered and tempered seeds as well as their IR treated ones particularly samples treated at 150 and 250^0 C. In untempered samples, water absorption capacity increased from 2.29 to 2.90, 2.34 to 2.88 and 2.40 to 2.82 g/g in control and IR treated seeds at 150 and 250^0 C respectively during 12 months of storage. Similarly, untempered and tempered seeds treated at 150 and 250^0 C and their control samples also encountered significant increase ($p \leq 0.05$) in oil absorption capacities on storage up to 12 months (Table 6). Ojimelukwe et al., (1999) also reported a significant increase in both water and oil absorption capacities of infested cow pea flour. However, treatment of the seeds at 350 and 450^0C resulted in a significant decrease ($p \leq 0.05$) in water and oil absorption capacities of both untempered and tempered seeds during storage up to 12 months. In untempered IR treated seeds, water as well as oil absorption capacities respectively decreased from 2.46 to 2.11 & 1.35 to 1.10g/g at 350^0 C and 2.50 to 2.08 & 1.42 to 1.10 g/g at 450^0C. Tempered seeds also followed a similar pattern of decrease of the same during storage up to 12 months. Nwosu et al*.,* (2011) also reported a decrease in both water and oil absorption capacities of Achi flour when stored at different storage conditions for 4 months.

3.7 Changes in uric acid content

Uric acid, a major component of insect excreta has been used as an index of insect infestation in grains (Combs, 1963) and it increases as the infestation progresses with time. The uric acid contents of untempered and tempered black gram seeds as well as their respective control samples during 12 months storage is exhibited in the Table 7. Initially, a negligible amount of uric acid (0.55-0.62mg/100g) has been reported in the untempered and tempered seeds of black gram. During storage, with the increase in insect population particularly in control and IR treated samples at 150 and 250^0C there was a significant increase ($p \leq 0.05$) of uric acid contents in both untempered and tempered seeds. In the control untempered and tempered infested samples, uric acid content increased from 0.55 to 33.90 and 0.62 to 38.23 mg/100 g respectively during 12 months of storage. Jood and Kapoor (1993) also reported a significant increase in the uric acid contents in wheat, maize and sorghum grains with the increase in the percentage of infestation. Samples treated at 150^0C also showed a similar trend of increase of uric acid contents. In the IR treated seeds at 250^0C, though the uric acid contents were found significantly high ($p \leq 0.05$), but found comparatively less than the control and 150^0 C IR treated ones and it increased from 0.55 to 22.52 mg/100g in untempered seeds and 0.62 to 24.58 mg/100g in tempered seeds. Adult insects started piercing and coming out of seeds have created voids, and seeds showed signs of damage after 3 months of storage, especially in control and IR treated samples at 150^0C and their uric acid content exceeded the permissible limit (<10mg/100g) with the corresponding depletion in the density (Table 4) of the seeds. However, in samples IR treated at 250^0C, the uric acid contents were found with in the permissible limit (7.68 and 9.45 mg/100g in untempered and tempered samples respectively) up to 6 months of storage. Through out the storage period, both in untempered and tempered seeds treated at 350 and 450^0C, visual inspection of the seeds were carried out periodically and found no signs of damage by insects and their uric acid contents showed slight variations during the entire storage period.

4.0 Conclusions

IR treatment protocol was developed for the disinfestation of black gram seeds during storage. Control as well as IR treated seeds (both untempered and tempered) at 150^0C were found infestation free up to 3 months of storage and samples treated at 250^0C up to 6 months. Infested samples showed significant ($p \leq 0.05$) decrease in seed weight, bulk density and significant ($p \leq 0.05$) increase in moisture, water and oil absorption capacities and uric acid contents as the storage period progressed. Though, the control and IR treated samples at 150 and 250^0C have become unfit for consumption due to infestation, studies were continued to check the maximum extent of infestation till the termination of the storage period. Untempered samples have not exhibited major changes in their rheology up to 350^0C and showed 87% germination capacity. Samples treated at 450^0C have shown only 46% germination capacity and its rheology was also affected due to heat treatment. On the other hand, tempered samples have shown a tremendous reduction in the germination percentage at all the temperatures of IR treatment, even though their rheological changes found almost comparable to untempered samples up to 350^0C. Keeping in view the changes in rheology, germination and extent of infestation, IR treatment of untempered samples particularly at 350^0 C can provide an effective and environmental friendly, chemical free disinfestation technique without affecting the product quality significantly.

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Table 1: Changes in rheological characteristics (RVU) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp (^{0}C)		Breakdown	Final	Setback	Pasting Temp
Control	Untempered	30.49^d	80.23^f	20.94^e	82.11^e
	Tempered	34.02^g	82.45^h	21.32^f	82.90^f
150	Untempered	30.05^d	80.01^f	20.76^e	81.19^c
	Tempered	33.56^g	81.70^g	21.01^f	82.21^e
250	Untempered	29.56^c	78.76^d	19.76^d	81.01^c
	Tempered	32.98^f	80.05^f	20.45^e	82.12^e
350	Untempered	29.01^c	78.01^c	18.95^c	80.76^b
	Tempered	32.05^e	79.11^e	19.01^c	81.68^d
450	Untempered	20.11^a	69.12^a	12.15^a	80.02^a
	Tempered	27.45^b	74.32^b	16.44^b	81.01^c

Values with different superscripts in columns differ significantly ($p \leq 0.05$)
Values are mean of three determinations (n=3)

Table 2: Changes in moisture content (%) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp (^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	10.75^{ij}	10.94^{k}	11.92^{n}	12.65^{p}	13.56^{r}
	Tempered	15.21^{w}	15.42^{x}	16.12^{y}	16.89^{α}	17.62^{δ}
150	Untempered	10.50^{gh}	10.85^{jk}	11.25^{l}	12.03^{n}	12.99^{q}
	Tempered	14.72^{u}	14.98^{v}	15.47^{x}	16.28^{z}	17.02^{β}
250	Untempered	9.82^{e}	10.20^{f}	10.63^{hi}	11.42^{m}	12.24^{o}
	Tempered	13.88^{s}	14.35^{t}	14.96^{v}	15.52^{w}	16.25^{y}
350	Untempered	9.49^{bc}	9.61^{d}	9.98^{e}	10.46^{g}	11.23^{l}
	Tempered	13.02^{q}	13.42^{r}	13.90^{s}	14.33^{t}	14.76^{u}
450	Untempered	8.92^{a}	9.30^{b}	9.58^{cd}	9.80^{e}	10.26^{f}
	Tempered	12.11^{n}	12.69^{p}	13.00^{q}	13.49^{r}	13.97^{s}

Values with different superscripts differ significantly ($p \leq 0.05$)
Values are mean of three determinations (n=3)

Table 3: Changes in 1000 kernel weight (g) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp (^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	52.21^{rs}	50.90^{l}	42.35^{i}	35.02^{e}	28.07^{a}
	Tempered	53.70^{x}	50.42^{k}	42.26^{i}	36.77^{g}	29.82^{b}
150	Untempered	52.07^{qr}	50.88^{l}	41.20^{h}	35.50^{f}	30.49^{c}
	Tempered	53.42^{w}	50.20^{k}	42.46^{i}	34.47^{d}	30.65^{c}
250	Untempered	51.50^{n}	50.22^{k}	45.80^{j}	40.24^{y}	35.40^{f}
	Tempered	53.23^{w}	50.02^{k}	45.50^{j}	40.11^{y}	36.84^{g}
350	Untempered	51.72^{op}	51.55^{n}	51.40^{n}	51.27^{m}	51.18^{lm}
	Tempered	52.95^{v}	52.84^{v}	52.66^{u}	52.41^{s}	52.22^{rs}
450	Untempered	51.75^{op}	51.40^{n}	51.20^{m}	51.14^{lm}	51.05^{l}
	Tempered	52.36^{s}	52.20^{rs}	52.11^{qr}	51.94^{pq}	51.86^{p}

Values with different superscripts differ significantly ($p \leq 0.05$)
Values are mean of three determinations (n=3)

Table 4: Changes in bulk density (g/ml) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp(^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	0.90^{lm}	0.87^{kl}	0.82^{gh}	0.75^{de}	0.62^{ab}
	Tempered	0.92^{m}	0.89^{lm}	0.84^{hij}	0.75^{de}	0.60^{a}
150	Untempered	0.89^{lm}	0.87^{kl}	0.81^{g}	0.76^{def}	0.65^{b}
	Tempered	0.90^{lm}	0.87^{kl}	0.82^{gh}	0.76^{def}	0.64^{b}
250	Untempered	0.88^{kl}	0.86^{jk}	0.81^{gh}	0.74^{d}	0.70^{c}
	Tempered	0.88^{kl}	0.85^{ijk}	0.80^{g}	0.74^{d}	0.69^{c}
350	Untempered	0.85^{ijk}	0.84^{hij}	0.82^{ghi}	0.80^{g}	0.80^{g}
	Tempered	0.86^{jk}	0.84^{hij}	0.81^{gh}	0.80^{g}	0.79^{fg}
450	Untempered	0.83^{ghij}	0.82^{ghi}	0.82^{ghi}	0.80^{g}	0.79^{fg}
	Tempered	0.84^{hij}	0.83^{ghij}	0.82^{ghi}	0.80^{ghi}	0.78^{efg}

Values with different superscripts differ significantly ($p \leq 0.05$)
Values are mean of three determinations (n=3)

Table 5: Changes in water absorption capacity (g/g) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp(^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	2.29^{c}	2.38^{d}	2.55^{ef}	2.68^{gh}	2.90^{j}
	Tempered	2.42^{d}	2.50^{e}	2.68^{gh}	2.81^{ij}	2.99^{k}
150	Untempered	2.34^{c}	2.40^{d}	2.58^{f}	2.70^{gh}	2.88^{j}
	Tempered	2.52^{e}	2.58^{f}	2.79^{i}	2.89^{j}	2.97^{k}
250	Untempered	2.40^{d}	2.48^{e}	2.60^{ef}	2.72^{gh}	2.82^{ij}
	Tempered	2.60^{f}	2.68^{gh}	2.80^{ij}	2.88^{j}	2.97^{k}
350	Untempered	2.46^{de}	2.40^{d}	2.31^{c}	2.20^{b}	2.11^{a}
	Tempered	2.67^{g}	2.55^{ef}	2.45^{de}	2.32^{c}	2.20^{b}
450	Untempered	2.50^{e}	2.41^{d}	2.30^{c}	2.18^{b}	2.08^{a}
	Tempered	2.74^{ghi}	2.60^{f}	2.45^{de}	2.30^{c}	2.18^{b}

Values with different superscripts differ significantly (p≤0.05)
Values are mean of three determinations (n=3)

Table 6: Changes in oil absorption capacity (g/g) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp (^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	1.15^{ab}	1.20^{bc}	1.35^{ef}	1.44^{gh}	1.57^{i}
	Tempered	1.32^{ef}	1.40^{fg}	1.59^{j}	1.72^{l}	1.80^{m}
150	Untempered	1.20^{bc}	1.26^{cd}	1.35^{ef}	1.47^{gh}	1.61^{jk}
	Tempered	1.32^{ef}	1.42^{gh}	1.56^{ij}	1.66^{k}	1.73^{l}
250	Untempered	1.29^{de}	1.38^{fg}	1.46^{gh}	1.59^{j}	1.62^{jk}
	Tempered	1.40^{fg}	1.50^{hi}	1.66^{k}	1.70^{l}	1.81^{m}
350	Untempered	1.35^{ef}	1.30^{de}	1.22^{c}	1.16^{ab}	1.10^{a}
	Tempered	1.47^{gh}	1.40^{fg}	1.32^{ef}	1.25^{cd}	1.18^{b}
450	Untempered	1.42^{gh}	1.35^{ef}	1.26^{cd}	1.20^{bc}	1.10^{a}
	Tempered	1.50^{hi}	1.42^{g}	1.33^{ef}	1.24^{cd}	1.15^{ab}

Values with different superscripts differ significantly (p≤0.05)
Values are mean of three determinations (n=3)

Table 7: Changes in uric acid content of (mg/100g) of IR treated untempered and tempered black gram seeds at varying temperatures during storage at ambient conditions (15-35^{0}C)

IR Temp (^{0}C)		Storage Period (Months)				
		0M	3M	6M	9M	12M
Control	Untempered	0.55^{a}	3.45^{g}	12.90^{k}	20.40^{o}	33.90^{t}
	Tempered	0.62^{ab}	3.09^{f}	15.25^{m}	25.88^{r}	38.23^{u}
150	Untempered	0.55^{a}	3.07^{f}	11.20^{j}	18.88^{n}	31.23^{s}
	Tempered	0.62^{ab}	3.16^{f}	14.25^{l}	24.89^{q}	38.98^{v}
250	Untempered	0.55^{a}	2.07^{e}	7.68^{h}	13.14^{k}	22.52^{p}
	Tempered	0.62^{ab}	2.18^{e}	9.45^{i}	15.66^{m}	24.58^{q}
350	Untempered	0.55^{a}	0.62^{ab}	0.69^{bc}	0.72^{cd}	0.64^{bc}
	Tempered	0.62^{ab}	0.70^{bcd}	0.64^{b}	0.59^{ab}	0.64^{bc}
450	Untempered	0.55^{a}	0.70^{bcd}	0.68^{bc}	0.77^{d}	0.64^{bc}
	Tempered	0.62^{ab}	0.65^{bc}	0.69^{bc}	0.74^{cd}	0.72^{cd}

Values with different superscripts differ significantly (p≤0.05)
Values are mean of three determinations (n=3)

Figure 1: Effect of IR temperature on the germination capacity of black gram seeds at varying temperatures