THE EFFECT OF CO^{60} ON THE PHYSICAL AND PHYSICOCHEMICAL PROPERTIES OF RICE

Efeito da irradiação gama (Co^{60}) nas propriedades físicas e físico-químicas do arroz

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ABSTRACT

Owing to its chemical composition and production chain, rice is susceptible to contamination by fungi. Among other techniques, the application of gamma radiation has been suggested as a method to ensure food safety. However, such radiation can alter the chemical composition of the food. Thus, the objective of the present work is to evaluate the centesimal composition, caloric value, pH, total titratable acidity, and coloration of polished white rice subjected to different doses of Co^{60} gamma radiation (0 kGy, 6.5 kGy, and 7.5 kGy). The results demonstrated that while gamma radiation did not cause significant alterations in the centesimal composition, caloric value, and titratable acidity of the rice, increasing doses substantially decreased the pH and intensified the coloration. Under controlled radiation conditions, a 6.5-kGy dose can render rice safe for consumption without significantly compromising its physical and physicochemical properties.

Index terms: Food irradiation, food properties, food safety.

RESUMO

O arroz apresenta composição química e cadeia produtiva susceptíveis à contaminação por fungos. Entre outras técnicas, a aplicação de radiação gama tem sido sugerida como um método para assegurar a segurança dos alimentos. No entanto, esta radiação pode alterar a composição química do alimento. Assim, o objetivo do presente trabalho foi avaliar a composição centesimal, o valor calórico, o pH, a acidez titulável total e a coloração do arroz branco polido submetido a diferentes doses de radiação gama Co^{60} (0 kGy, 6,5 kGy e 7,5 kGy). Os resultados demonstraram que a irradiação gama não promoveu alterações significativas na composição centesimal, valor calórico e acidez titulável do arroz, porém foi substancial para promover uma diminuição do pH e intensificação da coloração, à medida que se aumentavam as doses. Sob condições controladas de irradiação, a dose de 6,5 kGy, pode tornar o arroz seguro para o consumo sem comprometer significativamente suas propriedades físicas e físico-química.

Termos de indexação: Irradiação de alimentos, propriedades dos alimentos, segurança alimentar.

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INTRODUCTION

Despite constant scientific and technological evolution, one of the enduring threats to grain quality and safety is the risk of fungal contamination. Rice, which is frequently consumed by populations worldwide, is susceptible to contamination by fungal microorganisms owing to its chemical composition and production chain. This represents a public health problem since potentially toxigenic fungi can produce secondary metabolites such as mycotoxins, which have harmful mutagenic, carcinogenic, and teratogenic effects in humans (ICMSF, 2000).

Considering that such toxic biometabolites are normally thermostable, remaining potent for a long period even in the absence of the fungi, control and prevention of mycotoxin formation is of mounting importance (KLICH, 2007).

Some investigations have highlighted the efficiency of different doses of gamma radiation in destroying toxic fungal species in various types of foods (AZIZ; MAHROUS, 2003). However, researchers continue to be concerned with identifying new conservation alternatives that will maintain the original qualities of the food.

According to Wiendl (1984), irradiation and other food processing techniques can alter the chemical composition and nutritional value of foods. The nature and extent of those changes depend on the type, variety, and composition of the foods, the radiation dose, and the environmental conditions during and after irradiation.

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In Brazil, food irradiation has been permitted under resolution-RDC No. 21 from 26 January 2001 on the condition that the maximum absorbed dose is lower than the dose which may compromise the functional properties and/or the sensorial attributes of the food, and that the minimum absorbed dose is sufficient to achieve the intended objective (BRAZIL, 2001).

Given the above considerations, the objective of this work was to evaluate the quality of rice, based on its chemical and physicochemical properties, after exposure to gamma radiation at doses previously established and recognized as effective in controlling fungi in cereal.

MATERIAL AND METHODS

Characterization of the Experiment

Seven samples of polished, long-grain fine white rice in 2 kg packages were randomly purchased at various commercial establishments. The packages were intact and indicated that the products were within their validity periods.

Each rice sample was homogenized and fractioned into 3 500-g subsamples, 2 of which would be exposed to different radiation doses, while the third would be used as a control (non-irradiated). To ensure uniform conditions during irradiation, all samples were conditioned in polyethylene plastic packaging, and then properly sealed and identified.

Irradiation

A Gammacell GB-127 IR- 214 (MDS Nordion, Canada) irradiator with a cobalt source (Co^{60}) was used to irradiate the rice samples at the Gamma Irradiation Laboratory (GIL) of the Nuclear Technology Development Centre (NTDC), Belo Horizonte, Minas Gerais. The radiation doses used were 0 kGy (control), 6.5 kGy, and 7.5 kGy; these doses were found to significantly reduce the fungal population in rice in a preliminary survey. The dose rate was 6.0 kGy/hour and the temperature was maintained at 25±0.3ºC., before, during, and after the irradiation process.

Centesimal Composition

In preparation for the physical and physicochemical analyses of the rice, samples were triturated in a TE 631/2 mill (Tecnal, Brazil), poured through a 250-mesh sieve, and stored in covered glass containers.

The moisture level, ethereal extract, crude protein and ash, based on the integral matter, were determined according to the methods used by the Association of Official Analytical Chemists (AOAC, 2006).

Moisture

Samples were oven-dried at 105° C to constant weight in order to determine the gravimetric moisture level of the rice, according to method 945.15.

Ethereal Extract

Continuous extraction with organic solvent (ethyl ether) in a Soxhlet apparatus was carried out for the ethereal extract, according to method 920.39.

Total Protein

The level of total nitrogen was determined by the micro-Kjeldahl apparatus. The protein level was obtained by multiplying the total nitrogen content by a conversion factor of 5.95, according to method 984.13.

Ash

The fixed mineral residue, i.e., ash, content was determined by incinerating the samples in a muffle furnace at 550°C until all the organic matter had burnt away, according to method 942.05

Total Fibre

The total fibre content was determined using the gravimetric methods after digestion described by Kamer and Ginkel (1952).

Glycidic Fraction

The glycidic fraction (total carbohydrates) was calculated and represented by (100 - % fat -% protein fraction - % fraction crude fiber - % ash) on a dry basis, according to method 991.43 (AOAC 1995).

Caloric Value

The caloric value was obtained using the Atwater conversion factors according to Osborne and Voogt (1978).

Determination of pH and Total Titratable Acidity (TTA)

To calculate the potential of hydrogen, an extract from 10 g of the rice sample triturated in 100 mL of distilled water was prepared. After 10 minutes in a magnetic agitator, the pH was determined by a reading of the liquid supernatant in a digital pH meter as described by Cecchi (2003).

To determine the titratable acidity, 2 drops of phenolphthalein solution were added to the same material used for measuring the pH, the sample was agitated, and NaOH (0.1 N) was titrated until a pink colouration was obtained (INSTITUTO ADOLFO LUTZ, 1985). The result was expressed in milliequivalents of NaOH per 100 g of sample.

Colour Determination

Instrumental colour analysis was performed using a Minolta CR-400 reflectance colorimeter (Minolta, USA) set to L*a*b* Colour Space mode. The difference in total colour was obtained using the following equation:

$$\Delta E^* = [(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$$

in which ΔE^* = total colour difference
ΔL = L control sample – L sample
Δa^* = a control sample – a sample
Δb^* = b control sample " b sample.

The standard values of the control sample were: L = 90.61, a = 0.34, and b = 6.66, respectively.

Statistical Analysis

The data were analyzed by analysis of variance (ANOVA) and mutually orthogonal contrasts at a significance level of 5% ($p < 0.05$) using R software (R DEVELOPMENT CORE TEAM, 2012), through the package ExpDes (FERREIRA et al., 2011).

RESULTS AND DISCUSSION

Centesimal Analysis

The ANOVA results of the centesimal composition and caloric value of the polished white rice subjected to controlled doses of gamma radiation (Co^{60}) are presented on table 1 and means for each treatment are shown on table 2.

As shown in tables 1 and 2, doses of 6.5 kGy and 7.5 kGy had no significant effect ($p>0.05$) on the chemical composition of rice, i.e. they result the same effect that control does. These results are in agreement with those obtained by Zanão et al. (2009) with irradiated rice. According to the Brazilian Table of Food Composition (USP, 2006), raw rice is composed of 12.33 g/100 g of moisture, 6.73 g/100 g of protein, 0.89 g/100 g of total lipids, 79.57 g/100 g of total carbohydrates, and 0.48 g/100 g of ash. In relation to the reference values, the results obtained here are within the expected levels.

The moisture level of rice is predominantly influenced by the drying process, packaging, and storing of the grain. Moisture greatly affects the quality of rice

Table 1 – Analysis of variance, significance, coefficients of variation, and average values of moisture, ethereal extract, crude protein, raw fibre, ash, and glycidic fraction, and caloric value of polished white rice subjected to gamma radiation (Co^{60}).

Cause of Variation	DF	Sum of Squares						
		Moisture	Ethereal Extract	Crude Protein	Raw Fibre	Ash	Glycidic Fraction	Caloric Value
Radiation	2	$0.298^{n.s.}$	$0.905^{n.s.}$	$0.352^{n.s.}$	$0.547^{n.s.}$	$0.864^{n.s.}$	$0.538^{n.s.}$	$0.382^{n.s.}$
Error	18							
Corrected Total	20							
CV (%)		4.94	26.57	5.35	41.13	35.85	0.89	0.84
General Average		12.01	0.71	7.70	0.30	0.48	78.8	352.39

n.s., Not significant at the 5% of probability by the F test
DF Degrees of freedom

Table 2 – Means for each treatment of polished white rice subjected to gamma radiation (Co^{60}).

	Moisture	Ethereal Extract	Crude Protein	Raw Fibre	Ash	Glycidic Fraction	Caloric Value
0 kGy* (control)	11.812	0.705	0.774	0.255	0.452	86.003	11.812
6,5 kGy*	12.301	0.734	0.752	0.325	0.490	85.398	12.301
7,5 kGy*	11.925	0.689	0.784	0.310	0.499	85.792	11.925

* averages coming from seven replications.

because it directly influences the chemical composition and development of microorganisms.

The average moisture level of the polished white rice samples (12.01 g/100 g) met the established maximum moisture limit of 14.50 g/100 g for raw rice recommended by the National Agency of Sanitary Surveillance (ANVISA) (BRAZIL, 2006) and is similar to the moisture values cited for raw rice in the literature (12.01 g/100 g to 13.2 g/100 g) (UNICAMP, 2006; USP, 2006).

The average lipid concentration of the polished white rice (0.71 g/100 g) was slightly higher than the values found by other authors (0.38 g/100 g–0.62 g/100 g) (ASCHERI et al., 2006). The lipid level of rice depends mainly on the variety of rice and the processing method. The extent of pericarp, perisperm, and aleurone layer removal influences the lipid values of most types of marketed rice.

The protein level of the polished white rice samples (7.32 g/100 g) was consistent with the average values found in the literature (6.73 g/100 g–8.72 g/100 g) (UNICAMP, 2006; USP, 2006; ZANÃO et al., 2009). In addition to the variety of rice, the protein level is likely related to the type of processing of the grain. According to Castro et al. (1999), rice grains undergo protein, vitamin, and mineral losses during processing because the fractions overlying the endosperm of the seed and the germ are removed.

Although food fibres have no caloric value because they do not undergo hydrolysis during digestion, fibres are related to several important physiologic functions in human organisms (SILVA et al., 2007). In the present study, gamma radiation did not influence the total fibre levels in the rice. The average amount of raw fibre in the irradiated rice samples was 0.3 g/100 g, which is similar to the values found by Castro et al. (1999) (0.5 g/100 g). Therefore, irradiation does not interfere with the total fibre level of rice.

The levels of ash in the rice in the present study (approximately 0.48 g/100 g) were similar to those observed in other studies of raw rice (0.34 g/100 g–0.45 g/100 g) (ASCHERI et al., 2002; CASTRO et al., 1999). Similarly, in a study examining the use of gamma radiation to eliminate rice pests, Zanão et al. (2009) found that that treatment type did not alter the ash levels in this cereal.

The polished white rice used in the present work had a total carbohydrate level of 78 g/100 g. This glycidic fraction concentration is similar to that found by other authors for raw rice grains, such as Ascheri et al. (2006) (80.4 g/100 g) and Borges et al. (2003) (77.33 g/100 g). Zuleta et al. (2006), who studied the chemical composition of rice exposed to radiation, also did not find a difference in the total carbohydrate composition.

The number of calories in a specific food item refers to the amount of energy stored in the chemical bonds that is liberated in the organism through metabolism and absorption of the nutrients in the digestive system (SILVA et al., 2007). As shown in table 1, the rice had an average caloric value of 351.81 g/100 g, which is similar to that found by Ascheri et al. (2002) (353.09 g/100 g).

pH and TTA

The results of the ANOVA on the pH and TTA of the polished white rice subjected to controlled doses of gamma radiation are listed in table 3.

There was no significant ($p > 0.05$) dose-related difference in the total acidity of the rice samples (Table 3). Grain lipids are susceptible to breakdown by lipase into free fatty acids and glycerol during processing and storage,

Table 3 – Analysis of variance, significance, coefficients of variation, average values and mutually orthogonal contrasts of pH and total titratable acidity of polished white rice subjected to gamma radiation (Co^{60}).

Cause of Variation	DF	Sum of Squares	
		pH	Total Titratable Acidity
Radiation	2	0.044*	0.509$^{n.s.}$
Error	18		
Corrected Total	20		
CV (%)		1.75	19.85
General Average		6.07	0.03
Contrasts		p-value (*t*)	-
0 kGy		0.033*	-
6.5 kGy / 7.5 kGy		0.168$^{n.s.}$	-

* Significant at the 5% of probability by the F test
n.s., Not significant at the 5% of probability by the F test and *t*-test

especially under high temperature and moisture conditions. As such, lipids favour the alteration of acidity that makes deterioration possible (SILVA et al., 2007). In addition, organic acids have been shown to influence the flavour, odour, colour, stability, and quality maintenance of rice (CECCHI, 2003). In the present study, controlling the temperature (25±0.3ºC.) and moisture level might have helped to preserve the lipids of the rice.

However, the pH of the rice was found to significantly differ in response to the radiation dose, with lower pH values observed at higher radiation doses. Table 3 presents the mutually orthogonal contrasts for the pH measurements of the rice samples submitted to gamma radiation.

According to the orthogonal contrasts (Table 3), a significant difference exists among the average pH at the 0-kGy dose and the average pH at the 6.5-kGy and 7.5-kGy doses. However, the radiation doses studied did not differ significant among one another. The average pH observed for the control dose (6.15) was slightly higher than the average pH for the 6.5-kGy and 7.5-kGy doses (6.08). Although the hydrogen potential of the rice in our study was slightly lower after irradiation, it was still within the pH range (6.0–6.4) observed by Augusto-Ruiz et al. (2003) in a study of polished white rice.

Colour

Colour is a sensory property attributed to the spectral distribution of light. Table 4 states the results of the ANOVA performed on the instrumental colour data of the white rice submitted to different gamma radiation doses.

According to Table 4, the variables L, a*, and b* altered significantly when the polished white rice was exposed to gamma radiation, as evidenced by the significance of ΔE^*. It is worth noting that a* produced a high variation coefficient, even under controlled experimental conditions. It happened due to the average is close to zero. Table 4 presents the average values of the variables L, a*, and b* for the polished white rice submitted to gamma radiation.

As shown in table 4, the average value of L for the 0-kGy dose (90.61) was higher than that found for the 6.5-kGy and 7.5-kGy doses (89.28). Thus, regardless of the dose used, the brightness of the rice decreased significantly ($p \leq 0.05$) with the application of gamma radiation; in other words, the samples became less luminous, or darker. However, Zanão et al. (2009) did not find significant differences for the variable L in rice samples irradiated with doses of up to 5 kGy, and reported a lower average L value (69.90) than that observed in the present study.

For variable a*, significant differences ($p \leq 0.05$) were found between the control and the 6.5-kGy and 7.5-kGy doses. The average value of a* in the 0-kGy dose (0.34) was 0.29 units higher than the a* in the 6.5-kGy and 7.5-kGy doses (0.05). However, there was no difference in a* between the 6.5-kGy and 7.5-kGy doses. This result agrees with that of Zanão et al. (2009) also found alterations in the variable a* in rice samples as a function of gamma radiation, with values of 0.9 (non-irradiated rice) to 1.6 (rice irradiated with 5 kGy). However, in the present study there

Table 4 – Analysis of variance, significance, coefficients of variation, and average values of the individual colour variables (L, a*, b*, and ΔE*) of polished white rice subjected to gamma radiation (Co^{60}).

Cause of Variation	DF	kGy	Sum of Squares □			
			L	a*	b*	ΔE*
Radiation	2		0.026*	0.000*	0.000*	0.000*
Error	18					
Corrected Total	20					
CV (%)			1.07	74.79	6.67	26.85
General Average			89.7	0.14	8.76	2.63
Average Values□		0	90.61^{a}	0.34^{a}	6.66^{a}	-
		6.5	89.32^{bA}	0.07^{bA}	9.57^{bA}	-
		7.5	89.25^{bA}	0.03^{bA}	10.04^{bA}	-

* Significant at the 5% of probability by the F test
□ Averages within a column followed by the same lowercase letter are not significantly different by the F test at the 5% probability level; □ averages within a column (only for irradiated) followed by the same uppercase letter are not significantly different by the F test at the 5% probability level
- averages coming from seven replications

was an inverse behavior: color a* decreased with irradiation. According to the justification of Yu and Wang (2007), gamma irradiation can generate free radicals in the macromolecules of starch, which are capable of hydrolyzing chemical bonds and thereby break down large molecules into smaller fragments of dextrin, changing its structure and consequently, its color.

The average value of b* in the 6.5-kGy and 7.5-kGy doses (9.80) was 3.14 units higher than b* in the 0-kGy dose (6.66). However, there was no significant difference ($p > 0.05$) in this variable between the 6.5-kGy and 7.5-kGy doses. Sirissontaralak and Noomhorm (2006) found that the b* value of a non-irradiated rice sample was 9.72, while a sample irradiated with a 2-kGy dose had a value of 14.66.

Lee (2007) highlighted that the colour intensity of food increases with radiation dose. Roy et al. (1991) affirm that radiation doses slightly above 5 kGy provoke alteration in the colouration of rice, contradicting the study by Sirissontaralak and Noomhorm (2006), in which significant colour changes were observed in rice even with low-dose radiation (0.2 kGy). According to the authors, the colour of rice changed from creamy white to yellowish with an increase in radiation dosage. Zanão et al. (2009) also noted colour alteration in irradiated rice, with more yellowish coloration at doses of 3.0 kGy and 5.0 kGy.

The observed colour alteration of the polished white rice suggests that a possible glycoside and peptide coupling breakdown (Maillard reaction) might have occurred during the irradiation. The colour change in the irradiated rice could also have been an indicator of melanoidin formation due to the oxidation of phenols (ROY et al., 1991). According to Lee (2007), gamma radiation produces free radicals and products of glycoside radiolysis capable of condensing and thus producing coloured products during and after the irradiation.

According Aquino et al. (2011), irradiation process eliminates the fungal growth on rice, however, only the irradiation treatment does not guarantee the quality of the product if one does not observe the good practices of storage. In this study, treatment with ionizing radiation at a dose of 4 kGy did not cause significant changes in the sensory properties just afeter the process, but the authors suggest further studies on the sensory properties in varying periods of storage, to assess the actual conditions of shelf life in the retail market.

CONCLUSION

The results demonstrate that gamma radiation (Co^{60}) does not significantly ($p < 0.05$) alter the centesimal composition and TTA of polished white rice. However, radiation significantly reduces pH and intensifies the coloration of exposed rice. The fact that irradiation does not alter the nutritional quality of the polished white rice is vere importance for the employment of the same guarantees for the safe consumption of this cereal.

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