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Effect of microwave energy on grain quality of four Spanish rice varieties

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Abstract

A microwave system can be used as an alternative method to methyl bromide to control rice storage pests. Four rice varieties *(Oryza sativa* L.) grown in Spain ('Bomba', 'Senia', 'Puntal' and 'Thainato') were irradiated with three levels of microwave energy (0, 70 and 100 J g^{-1}). Rice quality attributes were analysed to establish hypothetical quality changes in order to use microwave energy as an alternative method to control pests. Results of the factorial analysis showed that the analysed attributes differed more within varieties than among microwave treatments of the varieties, except for 'Thainato' which, after applying microwave energy of 100 J g^{-1}, presented a different adhesiveness from the other two treatments determined by factor 1 and 'Puntal' treated with microwaves presented a different water uptake and loss of solids in cooking water determined by factor 3 than the control. The increase in hardness and decrease in adhesiveness as a consequence of the microwave treatment could possibly damage rice quality. This aspect must be taken into account with this method. In conclusion, microwave energy can be used as an alternative method of insect control because it does not seriously affect rice quality. Microwave treatments did not leave undesirable residues and could be as effective at controlling insect infestation as any procedure currently available.

Additional key words: desinsectation, grain quality attributes, *Oryza sativa*.

Resumen

Efecto de la energía microondas sobre la calidad de cuatro variedades españolas de arroz

A fin de analizar la utilización de energía microondas como método alternativo al bromuro de metilo para el control de plagas en arroz almacenado, se irradiaron cuatro variedades de arroz *(Oryza sativa* L.) cultivadas en España ('Bomba', 'Puntal', 'Senia' y 'Thainato') con dos niveles de energía microondas (0, 70 y 100 J g^{-1}). Se analizaron las posibles modificaciones de los atributos de calidad del arroz debidos al empleo de energía microondas. Los resultados demuestran que existen más diferencias de los atributos de calidad entre las diferentes variedades que entre tratamientos microondas, únicamente 'Thainato' con el tratamiento de 100 J g^{-1} de energía microondas se diferenció de los otros dos tratamientos en el atributo adhesividad determinado por el factor 1 y 'Puntal' tratado con microondas se diferenció del control en los atributos absorción de agua y sólidos cedidos al agua de cocción determinados por el factor 3. El aumento de consistencia y la disminución de la adhesividad como consecuencia del tratamiento microondas podrían ser un posible peligro para la calidad del arroz a tener en cuenta con este método. Por tanto, se puede afirmar que la energía microondas puede ser un método alternativo de desinsectación, ya que no afecta de forma significativa a la calidad del arroz, no deja residuos y es tan efectiva como cualquier método de desinsectación disponible hoy día.

Palabras clave adicionales: atributos de calidad del grano, desinsectación, *Oryza sativa*

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Introduction

Methyl bromide is a powerful destroyer of the Earth's protective ozone layer. The phase out schedule for methyl bromide under the Montreal Protocol is 2005 in developed nations. The Polytechnic University of Valencia (Spain) has, therefore, started research programmes on rice desinsectation using microwave energy, in order to establish alternative methods to control storage rice pests.

The first study to control storage pests such as *Tribolium confusum* duVal., *Sithophilus granarius* L. and *Cryptolestes ferrugineus* Steph. by microwave energy was performed on wheat by Hamid and Boulanger (1969) with a commercial magnetron with an available power output of 1.2 kW at 2.45 GHz. Other authors concluded that the use of microwaves alone was not enough to guarantee uniform heating of rice. As a consequence, rice had to be heated to a temperature over 80°C in order to kill the species appearing *(Sithophilus oryzae* L., *Rhyzopertha dominica* F. and *Oryzaephilus surinamensis* L.) (Locatelli and Traversa, 1989).

Preliminary research at the Polytechnic University of Valencia to control storage rice pests by microwaves caused selective and uniform heating. The authors concluded that 60°C is the maximum permitted temperature for the rice and that this corresponded with 100 J g^{-1} of microwave energy that caused 100% insect mortality (Rubio *et al.*, 1998). Rice treated in this way was analysed to show the effect on quality attributes.

Rice grain quality is determined by four attribute groups (Barber and Benedito de Barber, 1975): composition, sensory characteristics, public health and attributes related to the adequacy of rice for industrial processes.

It is necessary to study the effect of microwave energy on attributes of rice quality to establish hypothetical quality changes in order to use microwave energy as an alternative method of pest control.

The grains of four rice varieties grown in Spain (‘Bomba’, ‘Senia’, ‘Puntal’ and ‘Thainato’) differ in size and shape and in degree of chalkiness, translucency, opacity and whiteness (Table 1). Research on the eating quality of these varieties has been done in Spain and all the varieties studied showed different quality attributes (Primo *et al.*, 1960, 1962; Benedito de Barber and Martínez, 1997). The aim of this work was to evaluate the possible effect of microwave treatments on rice quality of these four rice varieties.

Material and Methods

Each milled rice variety supplied by Valencian industries was irradiated by two levels of microwave energy so that three treatments (0, 70 and 100 J g^{-1}) per variety were analysed in order to establish changes in quality attributes. A laboratory microwave system was used to irradiate polypropylene containers with 100 g of milled rice. Microwave power was 1000 W at 2.45 GHz.

Attributes of rice quality were analysed with the following approaches:

— Moisture content was determined by the method 712 (ISO, 1968). Spanish regulations (BOE, 1980, 1984) indicate that 15% is the maximum level permitted to guarantee quality.

— Milled rice colour was measured to determine the effect of microwave energy on possible colour changes of rice varieties. Colour was determined on a Hunter Lab colorimeter D-25 and was determined by three indices (L, a, b). The reference colour was white (L=93.6; a=1.0; b=2.3).

— Gelatinization time is a characteristic of rice variety (AACC, 1983) and is, therefore, an important physico-chemical factor in rice variety differentiation (Ranghino, 1966). Gelatinization time of kernels was measured following the method 14864:1998E (ISO, 1998).

Table 1. Milled rice varieties characteristics

Variety	Type	L (mm)	a (mm)	Ratio L/a	Whiteness
Bomba	*Japonica*	5.0	2.9	1.7	chalkiness
Puntal	*Indica*	6.7	2.0	3.35	vitreous
Senia	*Japonica*	5.8	3.1	1.9	chalkiness
Thainato	*Japonica*	5.6	2.8	2.0	vitreous

Source: Castells (2001). L: grain length. a: grain width.

— Water uptake and loss of solids in cooking water was based on the procedure of Primo *et al.* (1962), modifying the cooking conditions: 10 g of each sample was added to 400 ml of boiling water on a resistance cooker.

— Paste viscosity was determined by the method 061 (AACC, 1983), using a Brabender viscoamylograph from C.W. Brabender Instruments. This measures and records viscosity changes that occur during heating, holding, and cooling of a starch-containing mixture. Viscosity points on the amylograph curve can be tabulated for rice characterisation: temperature of initial viscosity increase; temperature at peak hot paste viscosity; viscosity at peak hot paste; viscosity at 95°C; viscosity at end of holding period at 95°C; viscosity at 50°C; viscosity at end of cooling to 50°C; setback viscosity at 50°C, defined as viscosity at 50°C minus peak hot paste viscosity and total setback, defined as viscosity at 50°C minus viscosity at end of holding period at 95°C.

— Texture profile analysis of cooked rice. A TA-XT2i texture analyser was used according to the reports of Champagne *et al.* (1998) and Lyon *et al.* (2000), modified. Parameters recorded from the test were hardness and adhesiveness. Rice samples (16 samples per treatment/ variety combination) representing four microwave treated varieties at two levels of microwave energy and control, were cooked for 20 min in a cooker followed by 45 min post cooking periods by Regulation CEE N.º 2580/88 (OJ, 1988). The top 1 cm layer of cooked rice, and rice adhering to the sides of each cooker were not used. Cooked rice for sampling was taken directly from the centre of each pot. Three grains of warm rice were arranged in a single grain layer on the base plate. A one-cycle compression force program was used to allow the plate to travel the 90% distance return. Test speed was 0.5 mm s^{-1}. A 50 mm diameter cylinder plunger was employed. Ohtsubo *et al.* (1993) concluded that the texture of the rice grain changes remarkably, so texture measurements were repeated 16 times to ensure repetitivity and reproducibility of the results obtained.

The results of the treatments were statistically analyzed with Statgraphics 5.1 software. An ANOVA was performed considering microwave treatments and variety as factors, followed by LSD-test of the means, at a 95% significance level with two and three degrees of freedom in microwave treatment and varieties, respectively. Following this, a factorial analysis was carried out. This analysis was carried out on the basis of 12 samples on which all quality attributes were considered.

Table 2. Composition and cooking rice attributes of microwave treatments [1]

		Microwave energy		
		0 J g^{-1}	**70 J g^{-1}**	**100 J g^{-1}**
Moisture content (%)		13.4 ± 0.1^a	12.7 ± 0.1^b	12.6 ± 0.1^b
Colour	L index (milled grain)	81.2 ± 0.0^b	81.1 ± 0.0^c	81.4 ± 0.0^a
	a index (milled grain)	0.7 ± 0.0^a	0.7 ± 0.0^a	0.7 ± 0.0^a
	b index (milled grain)	17.5 ± 0.0^a	17.5 ± 0.0^a	17.6 ± 0.0^a
Water uptake (g 100g^{-1} milled rice) db[2]		310.2 ± 3.5^a	315.3 ± 3.5^a	317.5 ± 3.5^a
Loss of solids at the cooking water (g 100g^{-1} milled rice) db[2]		16.9 ± 0.2^a	17.1 ± 0.2^a	17.2 ± 0.2^a
Paste viscosity	T of initial viscosity increase (°C)	83.8 ± 0.3^a	84.4 ± 0.3^a	84.4 ± 0.3^a
	T at peak hot paste viscosity (°C)	95.0 ± 0.1^a	94.8 ± 0.1^a	95.0 ± 0.1^a
	Viscosity at peak hot paste (BU)[3]	913.8 ± 13.5^a	915.0 ± 13.5^a	945.0 ± 13.5^a
	Viscosity at 95°C (BU)[3]	875.0 ± 10.8^a	881.3 ± 10.8^a	896.3 ± 10.8^a
	Viscosity at end of holding period at 95°C (BU)[3]	595.0 ± 18.0^a	585.0 ± 18.0^a	597.5 ± 18.0^a
	Viscosity at 50°C (BU)[3]	1.201,3 ± 22.3^a	1.208,8 ± 22.3^a	1.228,8 ± 22.3^a
	Viscosity at end of cooling to 50°C (BU)[3]	1.145,0 ± 25.6^a	1.147,5 ± 25.6^a	1.172,5 ± 25.6^a
	Setback viscosity at 50°C (BU)[3]	318.8 ± 16.1^a	338.8 ± 16.1^a	347.5 ± 16.1^a
	Total setback (BU)[3]	603.8 ± 17.2^a	632.5 ± 17.2^a	631.3 ± 17.2^a
Texture profile	Hardness (g)	5.040,4 ± 89.3^c	5.300,9 ± 89.3^b	5.705,0 ± 89.3^a
	Adhesiveness (area negative curve)	–35.68 ± 1.1^a	–28.73 ± 1.1^b	–29.56 ± 1.1^b

[1] Microwave treatments with the same transcript do not differ ($p < 0.05$). Analysis of variance is between treatments and varieties. Values show multiple range test comparison by LSD-method. [2] db: dry basis. [3] BU: Brabender units.

Results

Table 2 shows that moisture content decreased with microwave treatment (by 0.8% between rice with 0 and 100 J g^{-1} microwave treatments).

The L index presented significant differences between microwave treatments (maximum difference 0.3) (Table 2). Colour is a characteristic peculiar to each variety and was, therefore, different in all varieties (Table 3).

Regarding the gelatinization time of kernels, Table 4 shows that using microwave energy of 100 J g^{-1} 'Senia' and 'Puntal' increased their cooking time by more than 1 min (1 min 25 s and 1 min 54 s, respectively), 'Bomba' decreased its gelatinization time by more than 1 min (1 min 32 s). Gelatinization time of 'Thainato' suffered a slight modification (increased by 15 s).

Microwave treatment did not significantly modify water uptake and loss of solids to the cooking water (Table 2). These attributes were greater in 'Puntal' than in other varieties studied (Table 3).

Viscosity points of the amylograph curve of rice varieties were not significantly modified after the microwave treatments (Table 2, Fig. 1), but significant differences were found between rice varieties (Table 3) due to the fact that paste viscosity is a characteristic of variety. 'Puntal' *(indica* type) has the maximum value of total setback, but no differences were found compared to the other varieties in setback and viscosity at peak hot paste, except 'Thainato' which shows minimum values.

In the texture profile analysis (TPA) of cooked rice, hardness and adhesiveness varied with microwave treatment and rice varieties. Rice hardness increased slightly with microwave treatment. Adhesiveness decreased with microwave treatment, but there were no significant differences between 70 and 100 J g^{-1} microwave energy (Table 2). 'Bomba', 'Puntal' and 'Senia' did not show significant differences in hardness values, but 'Thainato' gave the significantly lowest hardness value. Adhesiveness was greater in 'Senia' and 'Thainato' (lower amylose content), and lower in 'Bomba' and 'Puntal' (higher amylose content). There were significant differences among all varieties (Table 3).

Table 3. Composition and cooking rice attributes of rice varieties (Bomba, Puntal, Senia and Thainato) irradiated with microwave energy 0, 70 and 100 J g^{-1} (1)

		Bomba	Puntal	Senia	Thainato
Moisture content (%)		12.9 ± 0.1^{b}	12.6 ± 0.1^{c}	12.6 ± 0.1^{c}	13.4 ± 0.1^{a}
Colour	L index (milled grain)	81.0 ± 0.0^{c}	81.2 ± 0.0^{b}	82.3 ± 0.0^{a}	80.4 ± 0.0^{d}
	a index (milled grain)	1.4 ± 0.0^{a}	0.7 ± 0.0^{b}	0.3 ± 0.0^{c}	0.4 ± 0.0^{d}
	b index (milled grain)	17.6 ± 0.15^{b}	18.0 ± 0.15^{a}	16.8 ± 0.1^{c}	17.7 ± 0.1^{b}
Water uptake (g 100g^{-1} milled rice) db^{2}		317.2 ± 4.0^{b}	368.5 ± 4.0^{a}	302.0 ± 4.0^{c}	269.7 ± 4.0^{d}
Loss of solids at the cooking water (g 100g^{-1} milled rice) db^{2}		16.8 ± 0.2^{b}	18.0 ± 0.2^{a}	16.5 ± 0.2^{b}	17.0 ± 0.2^{b}
Paste viscosity	T of initial viscosity increase (°C)	85.8 ± 0.4^{a}	83.8 ± 0.4^{b}	80.6 ± 0.4^{c}	86.6 ± 0.4^{a}
	T at peak hot paste viscosity (°C)	95.0 ± 0.1^{a}	94.9 ± 0.1^{a}	94.9 ± 0.1^{a}	95.0 ± 0.1^{a}
	Viscosity at peak hot paste (BU)^{3}	938.3 ± 15.6^{a}	945.0 ± 15.6^{a}	971.7 ± 15.6^{a}	843.3 ± 15.6^{b}
	Viscosity at 95°C (BU)^{3}	878.3 ± 12.5^{b}	913.3 ± 12.5^{ab}	953.3 ± 12.5^{a}	791.7 ± 12.5^{c}
	Viscosity at end of holding period at 95°C (BU)^{3}	651.7 ± 20.7^{a}	570.0 ± 20.7^{b}	553.3 ± 20.7^{b}	595.0 ± 20.7^{ab}
	Viscosity at 50°C (BU)**	1,383.3 ± 25.8^{a}	1,296.7 ± 25.8^{a}	1,028.3 ± 25.8^{c}	1,143.3 ± 25.8^{b}
	Viscosity at end of cooling to 50°C (BU)^{3}	1,316.7 ± 29.6^{a}	1,235.0 ± 29.6^{a}	980.0 ± 29.6^{c}	1,088.3 ± 29.6^{b}
	Setback viscosity at 50°C (BU)^{3}	286.7 ± 18.6^{b}	375.0 ± 18.6^{a}	430.0 ± 18.6^{a}	248.3 ± 18.6^{b}
	Total setback (BU)^{3}	728.3 ± 19.9^{a}	726.7 ± 19.9^{a}	486.7 ± 19.9^{b}	548.3 ± 19.9^{b}
Texture profile	Hardness (g)	5,774.9 ± 103.1^{a}	5,579.7 ± 103.1^{a}	5,509.0 ± 103.1^{a}	4,531.6 ± 103.1^{b}
	Adhesiveness (area negative curve)	–16.5 ± 1.2^{c}	–11.5 ± 1.2^{d}	–51.2 ± 1.2^{a}	–46.2 ± 1.2^{b}

[1] Attributes with the same transcript do not differ ($p < 0.05$). Analysis of variance is between treatments and varieties. Values show multiple range test comparison by LSD method. [2] db: dry basis. [3] BU: Brabender units.

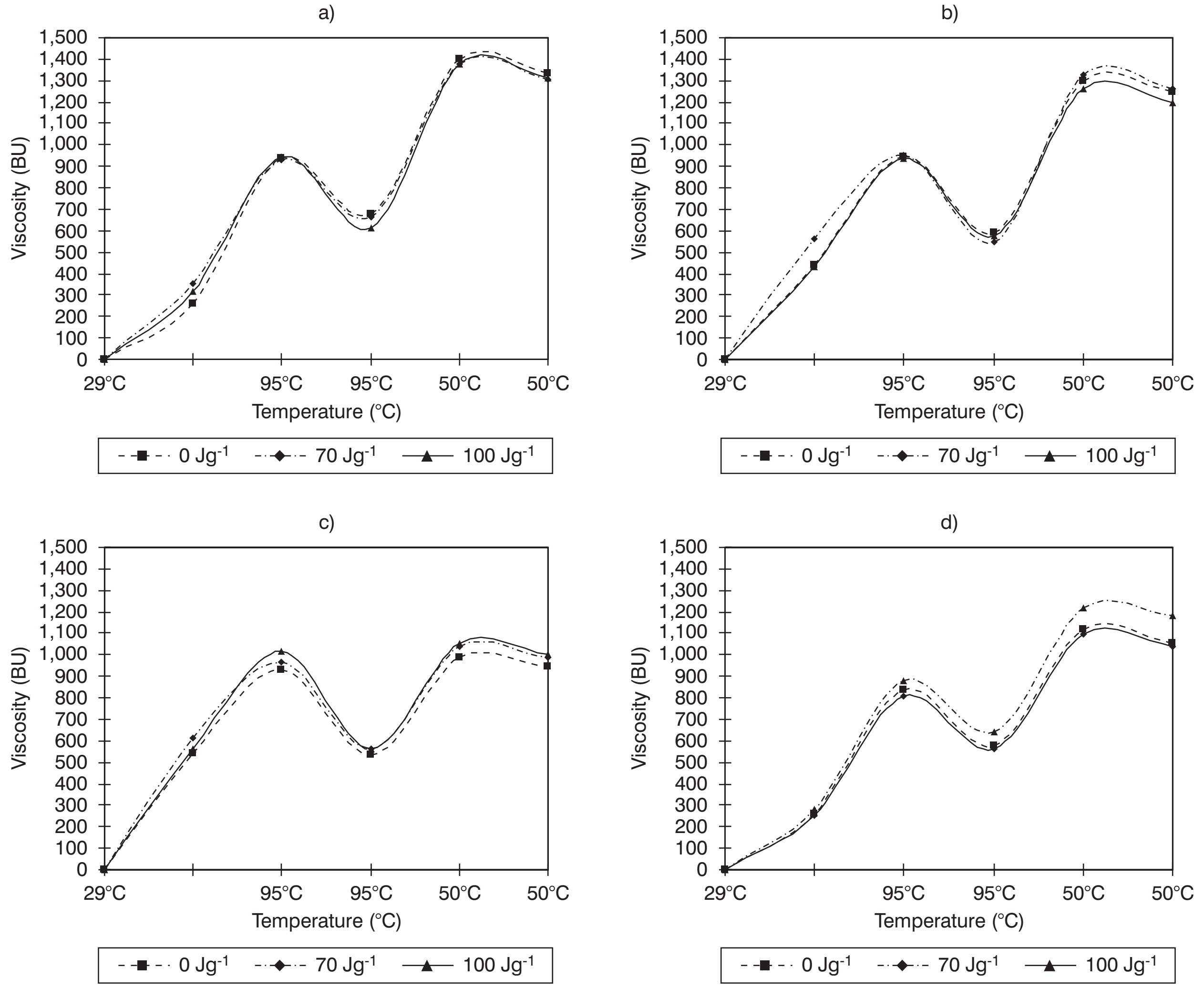
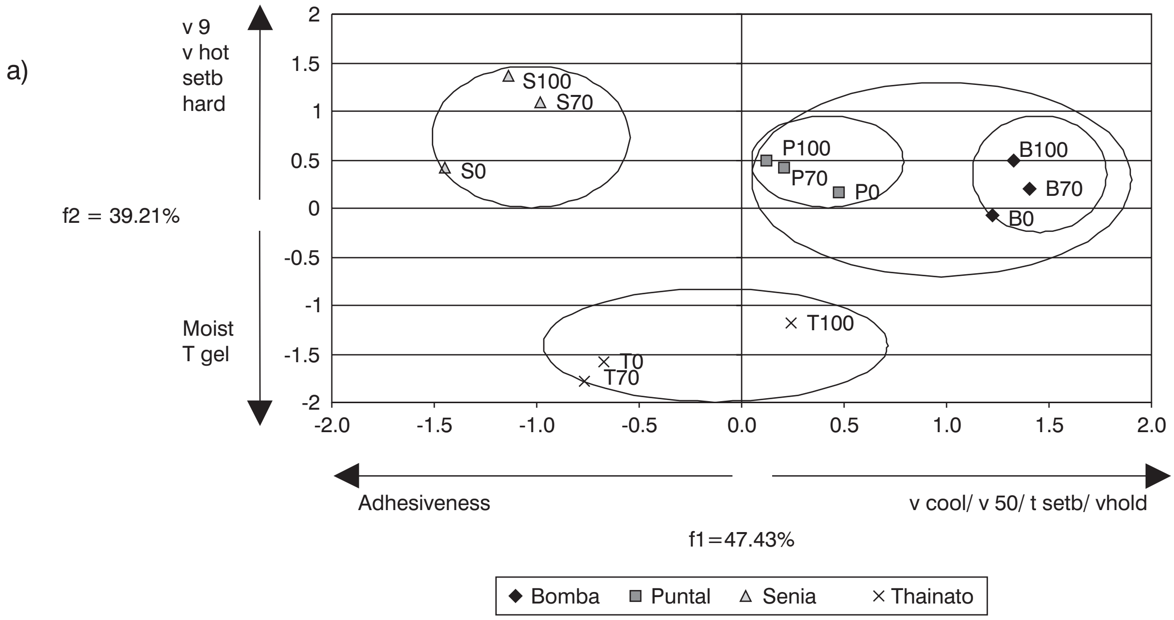


Figure 1. Amylograph curves of (a) 'Bomba', (b) 'Puntal', (c) 'Senia' and (d) 'Thainato' varieties irradiated with microwave energy (0 J g^{-1}, 70 J g^{-1} and 100 J g^{-1}).

Multivariate analysis

Fig. 2 shows the relationship between different varieties and microwave treatments. Each variety was classified into one of the three factors by applying multivariate analysis on the subset of quality attributes. The stepwise factorial analysis retained three factors which explain 100% of the variance. Factors 1 and 2 explain 86.65% of the variance. The attributes analysed differed more within varieties than within their microwave treatments. Regarding the grouping of varieties and microwave treatments by factors, 'Bomba' and 'Puntal' varieties were grouped by factor 2, i.e., within the attributes determined by this factor (hardness, viscosity at peak hot paste, viscosity at 95°C and setback). The 'Senia' variety is grouped by the attribute adhesiveness, determined by factor 1, as well as the 'Thainato' variety although with a greater difference. For factor 3, determined by water uptake and loss of solids in the cooking water, the control treatment is separated from microwave treatments for the 'Puntal' variety and for the 'Thainato' variety. The treatment using the highest microwave energy is separated from the other two treatments. The different treatments with 'Bomba' and 'Senia' varieties are grouped by factor 1, and are slightly different from the attributes determined by factor 3.



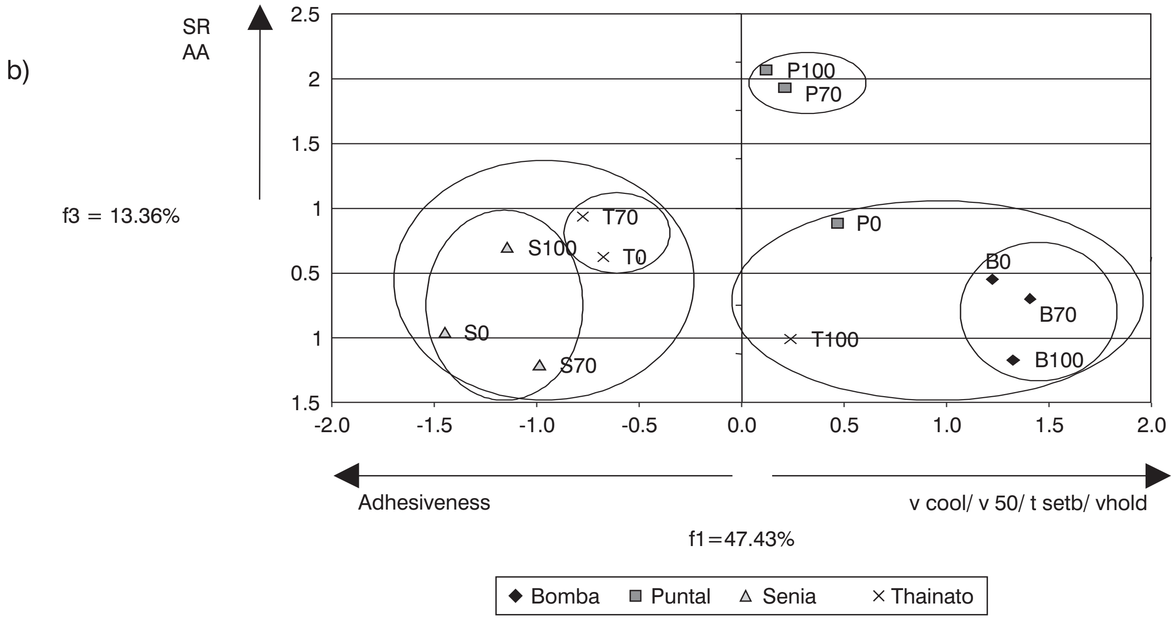


Figure 2. Distribution of rice samples in a) the factors 1 and 2, and b) 1 and 3. Factors are defined by factorial analysis and tendency of analytical variables. Factor 1 is determined by quality attributes: viscosity at end of cooling to 50°C (v cool), viscosity at 50°C (v 50), total setback (tsetb), viscosity at end of holding period at 95°C (v hold) and adhesiveness. Factor 2 is determined by quality attributes: viscosity at 95°C (v 95), viscosity at peak hot paste (v hot), setback viscosity at 50°C (setb), hardness (hard) and moisture (moist) and temperature of gelatinization (T gel). Factor 3 is determined by quality attributes: water uptake (AA) and loss of solids (SR) in cooking water. B = 'Bomba', P = 'Puntal', S = 'Senia', T = 'Thainato'; 0 = 0 J g^{-1}, 70 = 70 J g^{-1}, 100 = 100 J g^{-1}.

Table 4. Cooking time of rice varieties

Variety	Microwave energy (J g^{-1})	Cooking time
Bomba	0	22 min 12 s
	70	21 min 39 s
	100	20 min 40 s
Puntal	0	21 min 51 s
	70	22 min 30 s
	100	23 min 45 s
Senia	0	20 min 43 s
	70	21 min 27 s
	100	22 min 08 s
Thainato	0	20 min 08 s
	70	20 min 30 s
	100	20 min 23 s

Discussion

Moisture content is reported to influence the eating quality of rice (Ohtsubo *et al.*, 1993). Moisture content decreases by 0.8% with microwave treatment because microwaves interact with water molecules increasing temperature and drying the grain. Moisture content was different in each variety due to other factors (cropping season, storage temperature, growing location), since no irradiated varieties showed different moisture content. A moisture content of 12% is acceptable but a decrease in moisture of around 1% means the loss of 1 kg of rice for each 100 kg. This is, therefore, an important factor that can have a significant economic repercussion if rice is treated with microwave energy.

Milled colour is an important quality attribute that determines consumer acceptation (Benedito de Barber *et al.,* 1994). Generally, this is a subjective evaluation performed by the human eye. Microwave treatment slightly modified grain lightness (L) making it a little darker, although these changes were minimal, and probably not detectable by the consumer.

Water uptake changes are related with grain size and shape, long grain varieties show greater water uptake than medium and short grain varieties (Primo *et al.*, 1960; Bhattacharya and Sowbhagya, 1971). This agrees with the results obtained, as 'Puntal' (long grain variety) shows a greater water uptake. However, water uptake is primarily related to amylose content and amlyose content is not directly related with grain size and shape (Primo *et al.*, 1960). Loss of solids in cooking water is a quality attribute which explains variety cooking behaviour (Barber, 1979). Grain storage decreases the loss of solids in the cooking water (Primo *et al.*, 1962; Benedito de Barber and Martínez, 1997). Generally, long grain varieties show greater water uptake and less loss of solids than medium or short grain varieties (Primo *et al.*, 1960). In our case this did not occur, because in the control the long grain variety, 'Puntal', showed a greater loss of solids (transferred) to the cooking water than the other varieties. This can, therefore, not be explained by the effect of microwave energy. Neither water uptake nor loss of solids to the cooking water, are affected by microwave treatment.

Paste viscosity parameters play an important role in estimating the eating, cooking and processing quality of rice (Juliano, 1985; Shu *et al.*, 1998; Bao and Xia, 1999). The gelatinization temperature, maximum viscosity and 'breakdown' were reported to be suitable indices for the eating quality of rice (Primo *et al.*, 1960; Cagampang *et al.*, 1973; Ohtsubo *et al.*, 1993; Bao and Xia, 1999). Viscosity points of the amylograph curve of rice varieties were not modified by microwave treatment. Viscosity at peak hot paste and setback is lower in *indica* than *japonica* type rices and total setback is greater (Benedito de Barber and Martínez, 1997). Paste viscosity behaviour of the 'Bomba' variety *(japonica* rice) is similar to that of the *indica* type rice when the paste is cooled (breakdown) (Benedito de Barber and Martínez, 1997). This agrees with the results obtained. The paste viscosity parameters are not affected by microwave treatment.

Eating quality is determined mainly by the texture of the cooked rice (Primo *et al.*, 1960; Cagampang *et al.*, 1973; Barber, 1979). Cooked rice texture is difficult to evaluate and is influenced by many factors such as growing location, fertilizer application, degree of milling, storage conditions, physicochemical properties, final moisture, cooking method and rice variety (Champagne *et al.*, 1998; Lyon *et al.*, 2000). Several authors reported that the main factor that affects cooked rice texture is amylose content (Barber, 1979; Villareal *et al.*, 1994). High amylose varieties seem to be harder than those of intermediate and low amylose content (Barber, 1979; Sandhya and Bhattacharya, 1989; Ohtsubo *et al.*, 1993). It is agreed that there are secondary differences among varieties that have similar amylose contents (Barber, 1979; Juliano, 1985; Ohtsubo *et al.*, 1993). Later research suggested that cooked rice texture was largely determined by the fine structure of amylopectin molecules (Primo *et al.*, 1960; Radhika *et al,* 1994). Nevertheless, the results show that there are no significant differences between varieties, except for the 'Thainato' variety which showed lower hardness values. This can be explained by many factors which have an influence on texture-value, as mentioned above. Adhesiveness was higher in medium grain varieties ('Senia' and 'Thainato') with lower amylose content and higher in 'Puntal' (long grain variety) and 'Bomba' which has a high amylose content, despite having short grains. Differences in the water content of cooked rice following different cooking methods may possibly explain variations in the texture of the cooked rice obtained (Juliano and Pérez, 1983).

The microwave treatment slightly modified texture values, increasing hardness and decreasing adhesiveness. This variation would explain grains being slightly harder and less sticky after exposure to 100 J g^{-1}energy. This could be explained by the fact that the optimal cooking time is modified with microwave treatment, increasing cooking time in 'Puntal' and 'Senia' varieties and decreasing it in the 'Bomba' variety. Multivariate analysis reveals greater differences between varieties than between microwave treatments within each variety. However, few differences are apparent between microwave treatments for the varieties considered.

The microwave energy required to control rice storage pests is 100 J g^{-1} and the maximum rice temperature reached is 60°C (Rubio *et al.,* 1998). Each variety has specific characteristics, but the specific conditions of each crop, the drying and/or storage processes will facilitate different behaviours. Therefore, microwave energy could be considered as a new factor which contributes to these behavioural differences. The changes are not sufficient to cause consumer rejection of the product, and consumers are also responsible for evaluating the cooking attributes. Microwave treatments leave no undesirable residues and can be as effective at controlling insect infestation as any procedure currently available.

At present, the mortality of weevils in industrial furnaces is being investigated and, so far, preliminary results have been quite satisfactory. Further research work will be carried out to compare rice quality changes produced by an industrial prototype working within the rice production process.

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References

AACC, 1983. Amylograph method for milled rice. In: Approved methods of the American Association of Cereal Chemists. St Paul, MN, USA.

BAO J.S., XIA Y.W., 1999. Genetic control of paste viscosity characteristics in *indica* rice *(Oryza sativa* L.). Theor Appl Genet 98, 1120-1124.

BARBER S., 1979. La calidad del grano de arroz en los programas de mejora vegetal. Rev Agroquím Tecnol Aliment 19(3), 314-326.

BARBER S., BENEDITO DE BARBER C., 1975. Quality criteria of rice post harvest utilization. X International Congress of Nutrition, Kyoto, Japan, 3-9 August. pp. 187-191.

BENEDITO DE BARBER C., MARTÍNEZ J., 1997. Criterios de calidad del arroz para la industrialización y el consumo. In: Jornadas del Arroz. Ed. Fundación Valenciana de Estudios Avanzados, Valencia, Spain, pp. 111-120.

BENEDITO DE BARBER C., BARBER S., MARTÍNEZ J., 1994. Quality of temperate rice in Europe. Proc Temperate Rice Conference. Yanco, New South Wales, Australia, 1, pp. 187-191.

BOE, 1980. Orden de 12 de noviembre por la que se aprueba la Norma de Calidad para el arroz envasado con destino al consumo interior. Spanish Official Bulletin of the State, 19/11/1980.

BOE, 1984. Orden de 18 de abril por la que se modifica parte de la Orden del 12 de noviembre (BOE de 19 de noviembre de 1980) en lo referente a las tolerancias permitidas en las variedades de arroz de grano medio y semi-largo. Spanish Official Bulletin of the State, 26/4/1984.

CAGAMPANG G.B., PÉREZ C.M., JULIANO B.O., 1973. A gel consistency test for eating quality of rice. J Sci Food Agr 24, 1589-1594.

CASTELLS, J., 2001. Producción de semillas certificadas de arroz en la comunidad valenciana. Variedades cultivadas. Agrícola Vergel 131, 124-130.

CHAMPAGNE E.T., LYON B.G., MIN B.K., VINYARD B.T., BETT K.L., BARTON F.E., WEBB B.D., MCCLUNG A.M., MOLDENHAUER K.A., LINSCOMBE S., MCKENZIE K.S., KOHLWEY D.E., 1998. Effects of postharvest processing on texture profile analysis of cooked rice. Cereal Chem 75(2), 181-186.

HAMID M.A.K., BOULANGER R.J., 1969. A new method for the control of moisture and insect infestation of grain by microwave power. J Microwave Power 4(1), 11-18.

ISO, 1968. Determination of moisture content. Document International Organization for Standardization, 712: 1968(E).

ISO, 1998. Rice-evaluation of gelatinization time of kernels during cooking. Document International Organization for Standardization 14864: 1998(E).

JULIANO B.O., 1985. Criteria and test for rice grain qualities. In: Rice Chemistry and Technology. Am Assoc Cereal Chem St. Paul, Minessota. 774 pp.

JULIANO B., PÉREZ C.M., 1983. Major factors affecting cooked milled rice hardness and cooking time. J Texture Stud 14, 235-243.

LOCATELLI D.P., TRAVERSA S., 1989. Microwaves in the control of rice infestants. Ital J Food Sci 2, 53-62.

LYON B.G, CHAMPAGNE E.T, VINYARD B.T, WINDHAM W.R., 2000. Sensory and instrumental relationships of texture of cooked rice from selected cultivars and postharvest handling practices. Cereal Chem 77(1), 64-69.

OHTSUBO K., KOBAYASHI A., SHIMIZU H.,1993. Quality evaluation of rice in Japan. JARQ 27, 95-101.

OJ, 1988. Directive 88/2580/EEC of the Council of August 17th, establishing the modification criteria of the list of certain rice varieties cited in the Annex B of the Regulation (EEC) No. 3878/87. Official Journal of the European Union.

PRIMO E., CASAS A., BARBER S., 1960. Nuevos factores de calidad del arroz. Características de variedades españolas. Rev Cienc Apl 75, 312-321.

PRIMO E., CASAS A., BARBER S., BENEDITO DE BARBER C., 1962. Factores de calidad del arroz. VII. Ensayos selectivos basados en el envejecimiento: Propiedades organolépticas y fisicoquímicas del grano. Rev Agroquim Tecnol Aliment 2(3), 241-246.

RADHIKA K, SUBRAMANIAN R, ZAKIUDDIN S, BATTACHARYA K.R., 1994. Viscoelastic properties of rice-flour pastes and their relationship to amylose content and rice quality. Cereal Chem 71(6), 548-552.

RANGHINO F., 1966. Evaluation of rice resistance to cooking, based on the gelatinization time of kernels. Il Riso XV, 117-127.

RUBIO F.J., CATALÁ J.M., SÁNCHEZ D., 1998. Análisis de la viabilidad de la desinsectación del arroz blanco mediante la aplicación de radiación microondas. Proyecto final de carrera. Escuela Técnica Superior de Ingenieros de Telecomunicación. Valencia.

SANDHYA M.R., BHATTACHARYA K.R., 1989. Slurry viscosity as a possible indicator of rice quality. J Texture Stud 20, 139-149.

SHU QY., WU DX., XIA YW., GAO MW., MCCLUNG A., 1998. Relationship between RVA profile character and eating quality in *Oryza sativa* L. Sci Agric Sinica 31, 25-29.

VILLAREAL C.P., DE LA CRUZ N.M., JULIANO B.O., 1994. Rice amylose analysis by near-infrared transmittance spectroscopy. Cereal Chem 71(3), 292-296.