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# TEXTURE AND COLOR ANALYSIS OF LENTILS AND RICE FOR INSTANT MEAL USING IMAGE PROCESSING TECHNIQUES

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## ABSTRACT

Typical approaches for measuring color and texture properties are mostly time-consuming. An image-based method was used to evaluate texture and color in lentils and rice subjected to freeze-drying for an instant meal. Cooked and cooked freeze-dried rehydrated lentils and rice were analyzed by scanning electron microscopy. Texture properties were analyzed by texture analyzer and image analysis. Color was performed with a digital camera. Significant differences for color and texture ($P < 0.05$) were observed for cooked and cooked freeze-dried rehydrated lentils and rice. A linear trend with a linear correlation was applied for mechanical and image features. Results showed that image features such as contrast, correlation, energy and homogeneity calculated from Gray-level co-occurrence matrix had high correlations with mechanical features of hardness, adhesiveness, chewiness and gumminess for lentils, and for rice, mechanical features adhesiveness, gumminess and image features homogeneity and contrast. With this approach to quality, image processing techniques can be a useful tool.

## PRACTICAL APPLICATIONS

Development and innovation of new technologies are necessary, especially in food quality, because most instrumental techniques for measuring quality properties involve a considerable amount of manual work. Freeze-drying is not a new technique; it is expensive but an excellent option for instant meals. Different types of cereal and legumes are necessary to be studied so they can be included in instant meals. Therefore, by having enough knowledge on surface of cereals and legumes among the process, it will be possible by using image processing techniques to estimate quality parameters in cereals and legumes for consumer acceptance.

## INTRODUCTION

Cereal and legumes are one of the basic foods worldwide because they are inexpensive, full of nutrients and are used in a lot of different ways. They are rich in sources of complex carbohydrates, proteins, dietary fibers, vitamins, minerals and high energetic value. They also contribute to the intake of different minerals including calcium, iron and zinc (Wang *et al.* 2003; Costa *et al.* 2006).

Traditionally, lentils and rice are soaked beforehand to facilitate cooking and in the process; water penetrates through the seed coat to the cotyledons and distributes among starch and protein fractions. When water is uniformly distributed within the seed, the cotyledons become soft and uniform in texture (Hefnawy 2011; Zhang *et al.* 2014).

Some of the most important quality attributes of food products are texture, porosity, color, taste and nutrition. Among the different physical properties of food, color is considered the most important visual attribute in the perception of the product quality, because it is critically appraised by consumers and often is the basis for their selection or rejection (Carmo and Barbosa De Lima 2005). Consumers tend to associate color with texture, flavor, safety, storage time, nutrition and the level of satisfaction because of the fact that it correlates well with physical, chemical and sensorial evaluations of food quality. Along with the color, texture also plays an important role in overall acceptance of food quality by consumers (Segnini *et al.* 1999).

All the aforementioned physical and biochemical changes certainly cause a reduction in product quality and in process efficiency as well. Many authors have reported the application of freeze-drying as an important preservation method for food (Georgieva and Tsvetkov 2008; Ciurzyńska and Lenart 2011). The popularity of this method is based on some well-known advantages compared to competitive processes: sample stability at a room temperature, the easy reconstruction by the addition of water, the defined porous product structure, the reduction in weight, and the possibility of easy sterile handling.

Quality parameters are usually measured by conventional techniques, which include sensory and instrumental methods; although sensory analysis gives more complete description of product texture, there have been great interest in developing instrumental techniques because of their adaptability for quick, easy to use and industrial control protocols (Kono *et al.* 2015). Among the years image analysis has been applied in food quality because it is easy to use and economic. Texture in food is used to describe physical and sensory aspects of food; in image analysis, it is used as a way to describe the visual appearance of irregularities or variations in an image, which may be related to structure (Ong and Blanshard 1995). Textures do not have a simple or a unique mathematical definition, but refers in general terms to a characteristic variability in brightness that may exist at very local scales, or vary in a predictable way with distance or direction (Tournier *et al.* 2012). Gray-level co-occurrence matrix (GLCM) is probably one of the most frequently cited methods for the texture analysis of images (Du and Sun 2004). The texture of an image corresponds to the spatial organization of pixels in the image, and the co-occurrence matrix describes the occurrence of gray level between two pixels separated in the image by a given distance (Saini *et al.* 2014). GLCM results in the calculation of up to 14 textural features which can be expected to represent the textural characteristics of the image studied (Haralick *et al.* 1973).

Images for texture has be applied in meat (Naganathan *et al.* 2008; Kamruzzamana *et al.* 2012), fruits (Mendoza *et al.* 2012), cereal grain (Tahir *et al.* 2007), wheat (Barrera *et al.* 2013) and in chicken (Xiong *et al.* 2015) using different techniques such as simple macroscopic or miscroscopic light images, including confocal light microscopy, electron images (with either the transmission or scanning electron microscope), atomic force microscope images of surface and magnetic resonance. When microscopy techniques such as Scanning electron mircroscopy (SEM) and images analysis are used together, they become a powerful tool to evaluate microstructure changes of a product; cell size and number of cells can then be measured and quantified to form the projected image. A direct method for an objective measurement is likely to be the investigation of the product's structure and geometrical properties. Employing image processing with SEM, some important sensory attributes could be predicted by processing the surface and cross-section images of a product (Gao and Tan 1996).

The aim of the present research was to evaluate color and texture in lentils and rice submitted to freeze-drying for instant meals. Color and texture were performed on cooked and cooked freeze-dried rehydrated lentils and rice in order to evaluate microstructure, color and texture by using image processing techniques. On the other hand, data obtained by image were correlated with mechanical texture in order to evaluate the effectiveness of the method.

## MATERIALS AND METHODS

### Samples, Preparation for Freeze-Drying, Color and Texture Analysis

Samples of lentils (L) *cv* Pardina and rice (R) *cv* long grain were obtained at a local farmer. Preliminary evaluation to set treatment conditions, temperatures and water requirement was performed in lentils and rice in order to improve analysis. Optimized parameters were applied as follows: A 100 g of each sample was added to 946 mL of boiling water and cooked for 20 min for rice (CR) and 38 min for lentils (CL) after the water returned to boiling. Samples were cooled in water for 5 min, drained on paper towels to remove excess of water and spread on plastic trays and covered with aluminium fold until analysis.

For freeze-drying, noncontinuous equipment were applied (Rificor, Buenos Aires, Argentina). Parameters applied were the following: freezing temperature: −50 ± 1C (24 h); Drying process: 40 ± 1C at maximum vacuum (pressure: 0.346 Pa) during 48 h. Freeze-dried samples were vacuum packaged, individually identified and stored in a dark place at room temperature until analysis.

In order to analyze the texture and color of cooked freeze-dried rehydrated samples (CFDR), rehydration was performed with tap water at 98C. The duration of the rehydration process was fixed in 8 min for rice and 12 min for lentils, as after that time period there was no more absorption of water by the samples.

### SEM

Scanning electron microscopy was used for the observation of the microstructure of CR, CL, CFDRR (cooked freeze-dried rehydrated rice) and CFDRL (cooked freeze-dried rehydrated lentils). Rice grains and lentils seeds were longitudinal sectioned, using a scalpel; the cut was always performed in the same direction. Dehydration process was performed with ethanol series, acetone and dried. Samples were mounted on holders and coated with gold. Microscopic evaluation was performed using a scanning electron microscope (SEM 515, Philips, New York, NY). Observations of the samples at magnifications of 250–5000× were obtained for image analysis (Model Genesis Version 5.21.). Brightness and contrast are the most important variables that must be controlled during the acquisition of images; therefore, the values of these parameters were kept constant for each magnification during the process of image acquisition.

## Color Image

Pools of samples were illuminated using a lamp (model TL-D Deluxe, Natural Daylight, 18W/965, Philips) with a color temperature of 6,500 K (D65, standard light source) and a color-rendering index (Ra) close to 90%. The four fluorescent tubes (60 cm long) were situated 35 cm above the sample and at an angle of 45° with the sample. Additionally, light diffusers covering each lamp and electronic ballast assured a uniform illumination system. A color digital camera (CDC), Canon Eos Rebel T3i (Tokyo, Japan), was located vertically over the sample at a distance of 12.5 cm. The angle between the camera lens and the lighting source axis was around 45°. Lamps and CDC were inside a wooden box with internal walls that were painted black to avoid the light and reflection from the room.

Eight images from one side of each sample and eight regions of interest were taken on the matte black background using the following camera settings: manual mode with the lens aperture at f of 4.5 and speed 1/125, no zoom, no flash, 3,088 × 2,056 pixels resolution of the CDC and storage in JPEG format. The algorithms for preprocessing of full images, image segmentation and color quantification were processed by Adobe Photoshop cs6 (v13.0 Adobe Systems Incorporated.2012, San Jose, CA). *L*, *a* and *b* values were transformed to CIE $L^*$, $a^*$ and $b^*$. Values of $L^*$, $a^*$ and $b^*$ were used to calculate hue angle ($h^*_{ab}$), where $h^*_{ab} = 0°$ for red hue and $h^*_{ab} = 90°$ for yellowish hue and chroma ($C^*_{ab}$) in lentils and rice. Whiteness index (WI) was only calculated in rice.

$$h^*_{ab} = \text{arch tan}\left(b^*/a^*\right) \tag{1}$$

$$C^*_{ab} = \left(a^{*2} + b^{*2}\right)^{\frac{1}{2}} \tag{2}$$

$$\text{WI} = 100 - \left(\left(100 - L^*\right)^2 + a^{*2} + b^{*2}\right)^{\frac{1}{2}} \tag{3}$$

## Textural Profile Analysis

Textural profile analysis of CL, CR, CFDRR and CFDRL was performed individually using a texture analyzer (TA-XT-Texture Technologies Corp., Surrey, U.K.) with a 5-kg load cell using a two-cycle compression method. Samples were compressed to 3 mm with a time interval of 5 s at a speed of 5.0 mm/s. Results were reported as an average value. Hardness (HAR) was determined from the first test curve. Cohesiveness (COH), springiness (SPRIN), chewiness (CHEW), gumminess (GUM) and adhesiveness (ADH) were also determined. Samples were analyzed thrice.

## GLCM and Image Texture Analysis

Eight SEM image samples and eight regions of interest of each acquired SEM images were selected. Textural property was computed from a set of GLCM probability distribution matrices for a given image. The GLCM shows the probability that a pixel of a particular gray level occurs at a specified direction and distance ($d = 1$) from its neighboring pixels. GLCM is represented by $P_{d,\theta}(i, j)$ where counts the neighboring pair pixels with gray values *i* and *j* at the distance of *d* and the direction of θ (Haralick *et al.* 1973; Karimi *et al.* 2012).

Five image texture features (Correlation [COR], Energy [ASM], Homogeneity [HOM], Entropy [ENT] and Contrast [CON]) were calculated as follows (Eqs. (4)–(8)):

$$\text{CON} = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}(i-j)^2\, Pd,\theta(i, j) \tag{4}$$

$$\text{ENT} = -\sum_{i=0}^{n-1}\sum_{j=0}^{n-1} Pd,\theta(i, j)^2\, \text{Log}P(i, j) \tag{5}$$

$$\text{HOM} = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\frac{Pd,\theta(i, j)}{1+|i-j|} \tag{6}$$

$$\text{COR} = \frac{\left[\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(ij)P(i, j)\right]-\mu_x\mu_y}{\sigma_x\sigma_y} \tag{7}$$

$$\text{ASM} = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} Pd,\theta(i, j)^2 \tag{8}$$

where $u_x$, $u_y$, $\sigma_x$ and $\sigma_y$ are the means and standard deviations of $p_x$ and $p_y$.

## Statistical Analysis

Mean values were compared by Student's *t*-test, and regression equations, and correlation coefficients ($R^2$) between mechanical and image texture features were obtained using SPSS-Advanced Statistics 12 software (SPSS Inc., Chicago, IL).

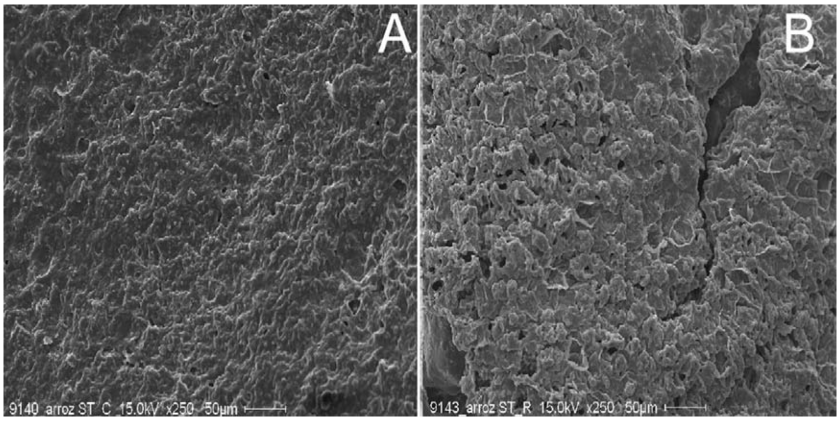

**FIG. 1.** SCANNING ELECTRON MICROGRAPHS PERFORMED AT 250 TIMES MAGNIFICATION OF A LONGITUDINAL SECTION OF COOKED (A) AND COOKED FREEZE-DRIED REHYDRATED (B) RICE

## RESULTS AND DISCUSSION

### SEM

Micrographs taken of longitudinal section of CR, CL, CFDRR and CFDRL are shown in Figs. 1 and 2.

CR (Fig. 1a) and CL (Fig. 2a) showed an organized structure, compacted and without gaps. During the cooking process, two simultaneous processes occur inside and outside the cotyledon cells; gelatinization of intracellular starch and denaturation of proteins that are accompanied by softening of the seeds as a result of plasticization or partial solubilization of the middle lamella, which leads to separation of individual cotyledon cells (Klamczynska *et al.* 2001; Wang 2008).

Bhatty *et al.* (1984) reported that micrographs (SEM) of cooked cereal and legumes showed a complete loss of cellular structure, while undercooked samples showed a lack of dissolution of the intercell wall material, including pectin.

CFDRR (Fig. 1b) and CFDRL (Fig. 2b) presented less gaps and was compact as CR and CL. The porosity of the structure depends on different factors like boiling time, pressure on the freeze-dryer and water uptake (Oikonomopoulou *et al.* 2011). Leelayuthsoontorn *et al.* 2006 reported that cooking conditions such as high temperature resulted in a larger pore size and bulkier starch matrix, especially in the inner layer endosperm. On the other hand, boiling caused deterioration only of the external appearance and softened the texture.

A general view of all micrographs showed that microstructure of CR, CL, CFDRR and CFDRL had similar structure, showing that porosity seemed to be gradually dispersed due to a fast and good rehydration process after freeze-drying.

### Color Analyses

Color values for CR, CL, CFDRR and CFDRL are shown in Table 1. Significant differences ($P<0.05$) were observed between CR and CFDRR, showing a positive effect for $L^*$, $b^*$, $C^*_{ab}$, WI and a negative effect for $a^*$ and $h^*_{ab}$. CL and CFDRL showed significant differences ($P<0.05$) for $L^*$ values.

CR had higher WI value when compared to CFDRR samples and brightness decreased in CFDRR. After rehydration process, CFDRR showed to be less softer, bigger and

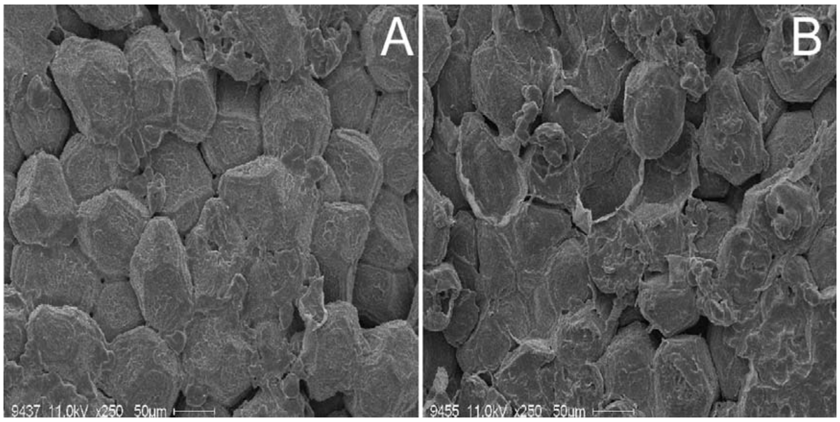

**FIG. 2.** SCANNING ELECTRON MICROGRAPHS PERFORMED AT 250 TIMES MAGNIFICATION OF A LONGITUDINAL SECTION OF COOKED (A) AND COOKED FREEZE-DRIED REHYDRATED (B) LENTILS

**TABLE 1.** COLOR PARAMETERS OF COOKED AND COOKED FREEZE-DRIED REHYDRATED RICE AND LENTILS

| | Color parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| Samples | $L^*$ | $a^*$ | $b^*$ | $h_{ab}$ | $C^*_{ab}$ | WI | df |
| CR | 94.29$^{a}$ | –6.50$^{a}$ | 2.61$^{b}$ | –21.87$^{a}$ | 7.00$^{b}$ | 90.96$^{a}$ | 7 |
| CFDRR | 82.80$^{b}$ | –6.97$^{b}$ | 4.01$^{a}$ | –29.95$^{b}$ | 8.04$^{a}$ | 81.01$^{b}$ | 7 |
| *P* value | 0.0001 | 0.0087 | 0.0030 | 0.0013 | 0.0002 | 0.0001 | |
| CL | 39.58$^{b}$ | 8.55 | 24.71 | 70.92 | 26.16 | – | 7 |
| CFDRL | 43.07$^{a}$ | 7.44 | 23.72 | 72.59 | 24.87 | – | 7 |
| *P* value | 0.0136 | NS | NS | NS | NS | – | |

Small letters in the same column indicate that means are significantly different ($P < 0.05$) related to condition effects (Student's *t*-test).

CFDRL, cooked freeze-dried rehydrated lentils; CFDRR, cooked freeze-dried rehydrated rice; CL, cooked lentils; CR, cooked rice; df, Freedom degree; NS, nonsignificant.

less whiter than CR. CFDRL samples had higher $L^*$ values when compared to CL. Statistical differences were obtained for chroma in CR and CFDRR. Chroma describes the vividness or dullness of a color (Kim *et al.* 2012).

Changes in color can be due to the dehydrating procedure which affects drying kinetics and rehydration kinetics among the process (Jiao *et al.* 2014). In rice, a higher drying temperature increases $b^*$ (yellowish) and WI values and decreases $L^*$ values (Karbassi and Mehdizadeh 2010). Changes in color can also be due to the freezing process before drying in rice and in lentils. In rice, it can provide a whiter product with a less uniform porous structure and higher bulk density (Sripinyowanich and Noomhorm 2011, 2013).

In lentils, moisture has influence in color; higher moister in the seed promotes starch gelatinization and protein denaturation and the development of darker pigments (Arntfield *et al.* 1997). Besides, discoloration is also due to tannins; tannins bind to proteins through hydrogen binding and hydrophobic interactions, thereby reducing their nutritional quality and changes in $L^*$ values (Hahn *et al.* 1984). Opoku *et al.* (2009) reported that temperature in the cooking process affects lentil color and higher temperatures decreases $L^*$ values. Color changes in rice and lentils can be associated to the above mentioned factors.

## Mechanical and Image Texture Analysis

Results obtained for mechanical and image textures are shown in Table 2. Statistical difference ($P < 0.05$) was obtained for CR, CL, CFDRR and CFDRL. A positive effect was observed for CHEW, GUM, HARD, ASM, ENT, CON, COR and HOM for CL and CFDRL; negative effect was observed for ADH for CL and CFDRL. CL had higher texture values when compared to FDRL.

CR and CFDRR showed a positive effect for GUM, HOM and CON and negative effect on ADH. CFDRR samples had higher GUM values when compared to CR. Therefore, CR had higher ADH when compared to CFDRR samples. Nonstatistical differences were obtained for CHEW, COH, HARD and SPIN for CR and CFDRR. CFDRR had higher CON and lower HOM values when compared to CR.

CFDRR and CFDRRL showed to have fast rehydration process; water easily reoccupied the empty space. Differences in samples can be because of water intake during rehydration (Rahman and Al-Farsi 2005), soaking (Joshi *et al.* 2010) and temperature of cooking or drying (Abu-Ghoush *et al.* 2015). Joshi *et al.* (2010) reported that soaking and temperatures affect hardness in cereal and legumes; higher cooking temperature decreases hardness and soaking reduces hardness. Reduction in hardness can be also attributed to its porous structure. Freeze-dried lentils and rice have a porous structure, and because of these properties, when samples are rehydrated results show lower hardness after rehydration. Final hardness also depends on the moisture content (Arntfield *et al.* 1997). Higher COH in rice is related to higher stickiness and HARD mostly related to roughness of mass (Meullenet *et al.* 1998).

Amylose content and gelatinization temperature are two of the most important factors that determine textural prop-

**TABLE 2.** MECHANICAL AND IMAGE TEXTURE OF COOKED AND COOKED FREEZE-DRIED REHYDRATED RICE AND LENTILS

| | Mechanical texture | | | | | | |
|---|---|---|---|---|---|---|---|
| Samples | ADH | CHEW | COH | GUM | HARD | SPRIN | df |
| CR | –1.25a | 10.01 | 0.76 | 10.41b | 15.54 | 0.85 | 7 |
| CFDRR | –7.79b | 11.53 | 0.74 | 12.60a | 16.88 | 0.92 | 7 |
| *P* value | 0.0001 | NS | NS | 0.0208 | NS | NS | |
| CL | –0.91a | 12.28a | 0.69 | 15.60a | 22.64a | 0.77 | 7 |
| CFDRL | –3.27b | 2.04b | 0.67 | 3.36b | 3.34b | 0.76 | 7 |
| *P* value | 0.0001 | 0.0001 | NS | 0.0001 | 0.0001 | NS | |

| | Image texture | | | | | |
|---|---|---|---|---|---|---|
| | ASM | ENT | CON | COR | HOM | |
| CR | 0.24 | 6.10 | 0.27b | 0.54 | 0.87a | 7 |
| CFDRR | 0.23 | 6.27 | 0.33a | 0.68 | 0.84b | 7 |
| *P* value | NS | NS | 0.0144 | NS | 0.0053 | |
| CL | 0.53a | 6.54a | 0.32a | 0.72a | 0.92a | 7 |
| CFDRL | 0.21b | 5.45b | 0.17b | 0.46b | 0.84b | 7 |
| *P* value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |

Small letters in the same column indicate that means are significantly different ($P < 0.05$) related to condition effects (Student's *t*-test).

ADH, adhesiveness; ASM, energy; CFDRL, cooked freeze-dried rehydrated lentils; CFDRR, cooked freeze-dried rehydrated rice; CHEW, chewiness; CL, cooked lentils; COH, cohesiveness; CON, contrast; COR, correlation; CR, cooked rice; df, Freedom degree; ENT, entropy, GUM, gumminess; HARD, hardness; HOM, homogeneity; NS, nonsignificant; SPRIN, springiness.

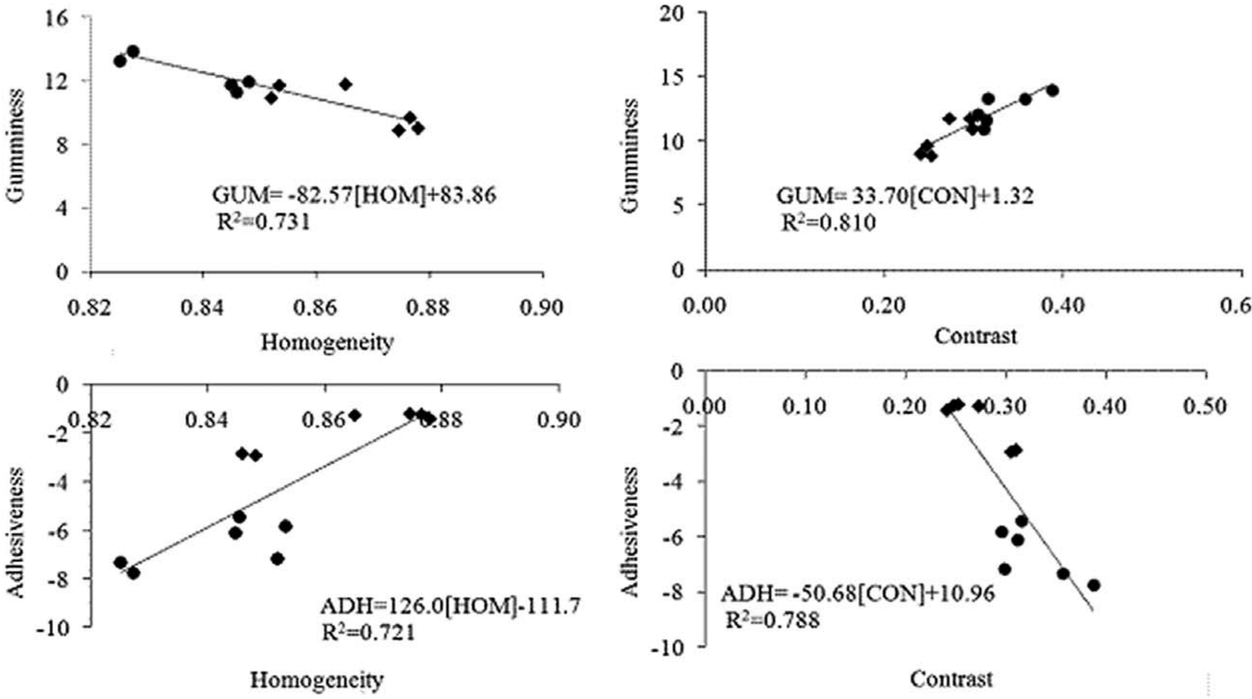

**FIG. 3.** CORRELATION COEFFICIENTS BETWEEN EACH MECHANICAL FEATURE GUMMINESS (GUM), ADHESIVENESS (ADH) VERSUS IMAGE FEATURES HOMOGENEITY (HOM) AND CONTRAST (CON) FOR COOKED (●) AND COOKED FREEZE-DRIED REHYDRATED (◆) RICE SAMPLES

erties. Elhady (2005) reported that in lentils (*cv.* Pardina) amylose content increased during cooking process. The stated author reported that the increment in starch content after cooking could be attributed to elimination of different antinutritional factors. Chung *et al.* 2011 reported that in four types of rice (long grain, Arborio, Calrose and Glutinous), long grain rice had the highest content in amylose and gelatinization temperature. Differences in the amylose content and gelatinization temperatures are attributed in part to the differences in the environmental conditions in which the crop is grown, particularly temperature (Singh *et al.* 2004).

A high value of HOM in CR shows improvement of uniformity and smoothness of the images (Karimi *et al.* 2012). Low values in CON represent diminishment of local variation of pixels. The softer the texture, the lower the contrast, which is due to lower pixel value difference between two neighbors. ASM and HOM values revealed improvement of uniformity and smoothness of the images of CL when compared to CFDRL.

Zheng *et al.* (2006) reported that in food analysis, when image texture is applied, some parameters are useful to evaluate quality factors such as energy because it shows the uniformity; contrast represents the local variations and correlations measure the linear dependencies and entropy indicate image order.

## Correlation between Mechanical and Image Texture

In order to evaluate the capability of image analysis for texture, a linear trend with a linear correlation under evaluated conditions were analyzed with mechanical features versus image features for lentils (ADH, CHEW, GUM and HARD versus CON, COR, ASM, ENT and HOM) and for rice (GUM and ADH versus CON, HOM).

In rice, the relation between mechanical texture GUM versus each image features HOM and CON showed good correlations coefficients (0.855 and 0.900, respectively). Similar behavior was found for mechanical feature ADH versus image features HOM and CON (0.850 and 0.888, respectively [Fig. 3]) in cooked and cooked freeze-dried rehydrated rice samples.

Lentils showed relation between mechanical feature HARD versus image features CON, COR, ASM, HOM and ENT (0.920, 0.886, 0.842, 0.901 and 0.898, respectively [Fig. 4.]); ADH versus CON, COR, ASM, HOM and ENT (0.793, 0.752, 0.858, 0.837 and 0.812, respectively [Fig. 5.]); GUM versus CON, COR, ASM, HOM and ENT (0.787, 0.747, 0.796, 0.821 and 0.773, respectively [data not shown]) and CHEW versus CON, COR, ASM, HOM and ENT (0.787, 0.743, 0.721, 0.760 and 0.793, respectively [data non shown]). Therefore, data of texture image analysis

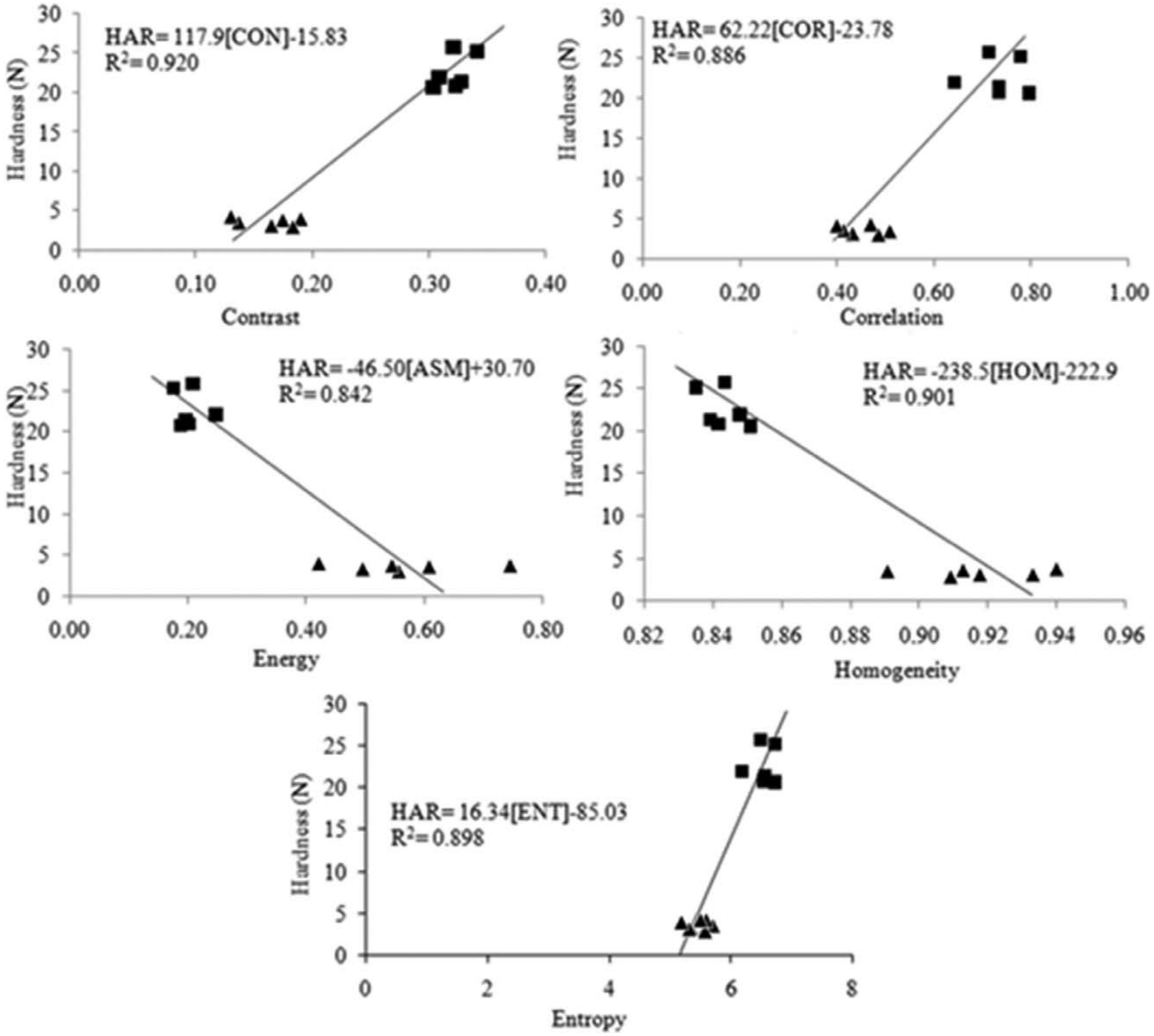

**FIG. 4.** CORRELATION COEFFICIENTS BETWEEN MECHANICAL FEATURE HARDNESS (HAR) VERSUS IMAGE FEATURE CONTRAST (CON), CORRELATION (COR), ENERGY (ASM), HOMOGENEITY (HOM) AND ENTROPY (ENT) FOR COOKED (■) AND COOKED FREEZE-DRIED REHYDRATED (▲) LENTILS SAMPLES

obtained showed that image features were very important to estimate mechanical texture in CR, CL, CFRR and CFRL. Multiple linear regressions (MLR) was also performed (Table 3). MLR between image and mechanical texture showed the capability of image properties to predict texture (coefficients of regression equation statistically significant [$P < 0.05$]).

Based on the resulting $R^2$ value, the models explained 92.6 and 93.4 (rice) and between 88.9 and 99.7% (lentils) of the variability associated with mechanical and image features. Data showed that in rice, image parameters such as HOM, CON and in lentils, ASM, ENT, CON, COR and HOM can be used to have an approach of texture.

## CONCLUSIONS

An imaging-based technique was developed to approach texture and color properties in rice and lentils for instant meals. Image texture analysis showed that rice homogeneity and contrast calculated from GLCM had high correlations with mechanical features such as gumminess and adhesiveness. For lentils, high correlations were found between mechanical features (hardness, adhesiviness, chewiness and

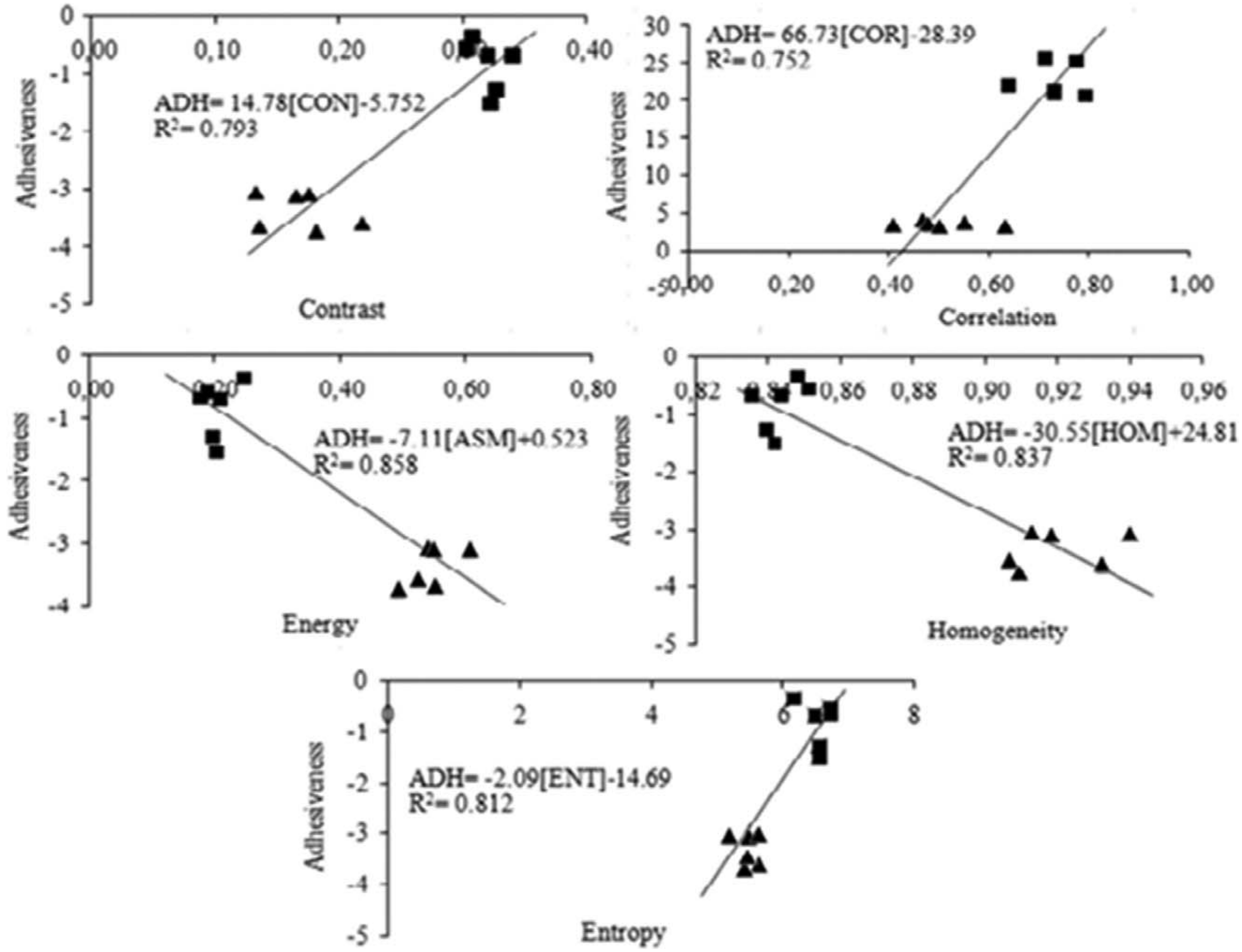

**FIG. 5.** CORRELATION BETWEEN ADHESIVENESS (ADH), CONTRAST (CON), CORRELATION (COR), ENERGY (ASM), HOMOGENEITY (HOM) AND ENTROPY (ENT) FOR COOKED (■) AND COOKED FREEZE-DRIED REHYDRATED (▲) LENTILS

gumminess) and image features (contrast, correlation, energy and homogeneity).

Image analysis showed to be a useful tool for lentils *cv* Pardina and in long grain rice because a rapid method for estimation of texture and color can be performed. On the other hand, we believe that in the future it will be possible to establish a general trend; for this, other grain and seed cultivars must be evaluated.

**TABLE 3.** MULTIPLE REGRESSION MODEL OF MECHANICAL AND IMAGE TEXTURE OF RICE AND LENTILS

| Sample | Parameter | MLR equation | *R* |
|---|---|---|---|
| Rice | ADH | ADH = –225.6 + 38.0 [CON] + 245.4[HOM] | 0.934 |
| | GUM | GUM = –28.5 + 45.1[CON] + 30.9[HOM] | 0.926 |
| Lentils | HARD | HARD = –91.6 + 153.0[CON] + 8.7[COR] + 45.4[ASM] + 8.1[ENT] – 4.6[HOM] | 0.997 |
| | ADH | ADH = –42.5 + 17.2[CON] – 4.4[COR] + 0.28[ASM] + 2.7[ENT]+ 25.4[HOM] | 0.934 |
| | CHEW | CHEW = –322.1 + 241.9[CON] + 10.9[COR] + 35.8[ASM] + 2.5[ENT] + 267.3[HOM] | 0.889 |
| | GUM | GUM = –383.1 + 288.6[CON] – 5.0[COR] + 16.9[ASM] + 8.3[ENT] + 323.3[HOM] | 0.928 |

ADH, adhesiveness; ASM, energy; CHEW, chewiness; CON, contrast; COR, correlation; ENT, entropy, GUM, gumminess; HARD, hardness; HOM, homogeneity.

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