Food Chemistry xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers

Yali Yang, Isabel Achaerandio, Montserrat Pujolà *

Departament d'Enginyeria Agroalimentària i Biotecnologia, Escola Superior d'Agricultura de Barcelona, Universitat Politècnica de Catalunya BarcelonaTech, Barcelona, Spain

ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 30 October 2015
Accepted 5 November 2015
Available online xxxx

Keywords:
Antioxidant activity
Baking
Boiling
Microwaving
Resistant starch
Texture

ABSTRACT

The different intensities of common culinary techniques (boiling, baking and microwaving) produce several changes that reduce the nutritional and physical properties of potatoes. This study evaluated the effect of those cooking methods on the quality of commercial potato tubers (Agata, Kennebec, Caesar and Red Pontiac). The higher weight losses were obtained for baking, but the potato softening depended on the cultivar. Color losses were independent of the intensity of the treatment; however, microwaving promoted a prompt starch gelatinization with respect to the other methods. The resistant starch retention of baking and microwaving was higher than that of boiling, and the maximum retention of bioactive compounds was obtained with the lower core temperature during boiling, as well as higher temperature and shorter baking time and the lower power and longer microwaving time. Principal component analysis revealed significant relationships between the instrumental and functional properties of cooked potatoes.

1. Introduction

Potatoes (*Solanum tuberosum* L.) are an important source of carbohydrates and are consumed widely in the developing world and in the developed world (Bordoloi, Kaur, & Singh, 2012). The potato tubers are commonly cooked before consumption, and the traditional and most popular cooking methods include boiling, frying and baking. It is well known that cooking treatments induce significant changes in the physical and chemical compositions to influence the concentration and bioavailability of bioactive compounds in potato tubers (Price, Bacon, & Rhodes, 1997). However, both positive and negative effects have been reported depending on the differences in the process conditions and in the morphological and nutritional characteristics of potato samples (Liu, Tarn, Lynch, & Skjodt, 2007).

Heat-treatment is a complex process that involves many physical, chemical and biochemical changes in food. In particular, during potato cooking, starch gelatinization occurs, which affects the palatability, digestibility and causes softening of the raw starch matrix. Heat is transferred into the potato tubers primarily by convection from the heating media (water) (Barba, Calabretti, Amore, Piccinelli, & Rastrelli, 2008). Different cooking conditions have significantly different effects on the properties of potato tubers.

The physical properties of potatoes are great affected by the heat treatments. Texture and color are considered very important parameters in the cooking quality of potato samples, and they may influence consumer purchase of these potato products (Turkmen, Poyrazoglu, Sari, & Velioglu, 2006; Waldron, Smith, Parr, Ng, & Parker, 1997). Changes in the texture are usually dramatic, which is due to the membrane disruption and the associated loss of turgor (Waldron et al., 1997). The texture of cooked potato has also been associated with dry matter, sugars, etc. Many attempts have been made to determine the relationship between the texture of cooked potato and the physical or chemical properties of potato starch (Kaur, Singh, Sodhi, & Gujral, 2002). Others changes in the potato tuber microstructure and texture during cooking have been mainly associated with the gelatinization behavior of starch through the cell wall, and the middle lamellae structural components also play a role (Alvarez, Canet, & Tortosa, 2001). Additionally, cooked potatoes usually exhibit poor color quality compared with fresh tubers because of browning (Turkmen et al., 2006).

The cooking treatment leads to an increase in the rate of starch hydrolysis by gelatinizing the starch and making it more easily available for enzymatic attack during digestion (Bordoloi et al., 2012). Mulinacci et al. (2008) reported that microwaving tends to reduce the starch availability for digestive enzymes, as shown

* Corresponding author at: Universitat Politècnica de Catalunya BarcelonaTech (UPC), Departament d'Enginyeria Agroalimentària i Biotecnologia, Campus Baix Llobregat, Edifici D4, C/Esteve Terradas, 8, 08860 Castelldefels, Barcelona, Spain.
E-mail address: montserrat.pujola@upc.edu (M. Pujolà).

http://dx.doi.org/10.1016/j.foodchem.2015.11.028
0308-8146/

by hydrolysis curves that are consistently lower than those obtained for boiled potatoes. This finding is observed because the crystallinity of potato starch increases during microwave irradiation, and boiling tends to destroy the crystalline structure. The starch molecules undergo several physical modifications depending upon the type of starch, and the severity of the conditions applied affected the content of resistant starch (Yadav, 2011). The resistant starch (RS) content and the effects of different cooking methods on the RS content have been on studied by several researchers (Mulinacci et al., 2008; Yadav, 2011). However, the results regarding the effect on the RS conflicted.

Apart from being a rich source of starch, potatoes contain small molecules and secondary metabolites that play an important role in many treatments (Friedman, 1997). Potatoes are good sources of natural antioxidants, such as vitamins, carotenoids, flavonoids and phenolic compounds. These natural antioxidants show potential actions against the risk of several age-related diseases, such as cancer, cardiovascular disease, cataract and macular degeneration (Chuah et al., 2008). Although the phenolic content has been extensively studied for raw potatoes (Rumbaoa, Cornago, & Geronimo, 2009; Stushnoff et al., 2008), there have been many discrepancies regarding the effect of heat treatments on the phenolics and antioxidant activity of potato samples, which could be due to the different processing conditions. Some literature has suggested that a shorter cooking time and lower temperature increased or did not change the total phenolic content and the antioxidant capacity (Blessington et al., 2010; Lachman et al., 2013; Mulinacci et al., 2008; Navarre, Shakya, Holden, & Kumar, 2010; Perla, Holm, & Jayanty, 2012).

Although there is some previous research on the effect of potato processing, very little information is available on the main components and the bioactive compounds. Thus, it is critical to understand the effect of such processing techniques on the activity and composition and physiochemical properties of potatoes. Therefore, we evaluated the effect of temperature and time of culinary treatments (boiling, baking and microwaving) on the nutritional components and physical properties of commercial potato tubers. The relationships between the different cooking treatments and the potato properties necessary for obtaining higher quality cooked potato products were also assessed.

2. Materials and methods

2.1. Samples

Four potato cultivars (*S. tuberosum* L.) that are grown and consumed worldwide (Agata, Caesar, Kennebec and Red Pontiac) were selected according to their cooking type, which is defined by the European Cultivated Potato database, and they were obtained from Mercabarna (Mercados de Abastecimientos de Barcelona S.A., Barcelona, Spain). The average weight of the potato tubers ranged from 175.09 to 337.60 g. The physical characteristics of cultivars were described in a previous research work (Yang, Achaerandio, & Pujolà, 2015).

2.2. Sample preparation

Approximately 18 kg of each potato cultivar of a similar size and weight were selected, washed with tap water and dried on paper towels. The potatoes were cooked with the peels. In this study, three cooking methods, boiling, baking and microwaving, at two different intensities (time–temperature) were evaluated in the four cultivars selected. Each individual experiment was conducted in triplicate. The cooking conditions were determined in a preliminary experiment for each heat treatment (data not shown). In all cooking processes they have been used whole un-peeled potatoes. The conditions used in each cooking processing were:

a. Boiling: The potatoes were boiled in the covered pan using the magnetic induction heating at 100 °C and relation potato/water (1:3) during 50 min (Bo100/50) or 60 min (Bo100/60) (the time was from the start point).
b. Baking: The potatoes were baked in a domestic hot-air oven during 60 min at 250 °C (Ba250/60) or 65 min at 220 °C (Ba220/65).
c. Microwaving: The potatoes were cooked in a domestic microwave oven at 700 W during 25 min (M700/25) or at 560 W during 35 min (M560/35).

To acquire the experiment data and to validate the heat transfer model, copper–constantan thermocouples (TC Direct, Spain) were used to measure the temperature during the heat treatments. The cooking value, C_{100}, relates the quality loss during a high-temperature thermal process to an equivalent cooking process at 100 °C, and the value was estimated using the equation,

$$C = \int_0^t 10^{\left[\frac{T-T_{ref}}{Z_Q}\right]} dt \quad (1)$$

where Z_Q (Z-value) and T_{ref} (reference temperature) represent the most heat-labile component. Generally, the reference cooking value is characterized by Z_Q = 33.1 °C and T_{ref} = 100 °C (Ling, Tang, Kong, Mitcham, & Wang, 2015).

After processing, the cooked potatoes were cooled for 1 h and the flesh and skin were separated and analyzed. A portion of the samples were lyophilized using a freeze-drying instrument (Cryodos-45, Terrasa, Spain), packed in plastic bags and maintained at −20 °C until further use.

2.3. Physical analysis

2.3.1. Weight loss and dry matter

The weight loss was expressed by the ratio of weight difference between the fresh and processed samples to the original weight. The dry matter was analyzed following the gravimetric method (AOAC 931.04). Briefly, 3 g of ground potato samples were dried at 65 °C until they were a constant weight. The dry matter content was calculated as g kg^{-1}. The analyses were conducted in triplicate.

2.3.2. Determination of shear force and texture profile analysis (TPA)

The shear force of the potato tissues was measured using the texture analyzer (TA.XT plus, Stable Microsystems, Godalming, UK) and a Warner–Bratzler probe. The potato samples were hand-peeled and then cut into strips (1 × 1 × 6 cm) with a stainless steel slicer. The test conditions were a speed of 1 mm s^{-1} and a target distance of 22 mm. The shear force was taken as the area under the curve (N). Six potato strips were used for each sample. The cooking degree was calculated by the ratio of the final shear force to the original shear force as a measure for the degree of cooking in the potatoes (Bourne, 1989).

The texture profile analysis (TPA) was determined with a 75 mm diameter cylinder probe. The potato cylindrical samples were obtained using a plastic cork broker with a diameter of approximately 19.0 mm. Each cylinder was subsequently trimmed to a length of 10.0 mm using a mechanically guided razor blade. The following parameters were set: a test speed of 0.83 mm/s and a rest period of 5 s between the two cycles. The maximum extent of deformation was 40% of the original length (Alvarez et al., 2001). According to the definitions of Bourne (1978), the TPA values for hardness (N), cohesiveness (dimensionless), springiness (mm) and chewiness (N × mm) were calculated from the

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

resulting force–time curve. Six potato cylinders were tested for each potato sample.

2.3.3. Determination of color

The color parameters were assessed with a MINOLTA tristimulus colorimeter, CR-400 model (Minolta camera, Osaka, Japan), in the CIELab space. The L^* (lightness), a^* and b^* were recorded. The parameters H° and C were calculated as $H^\circ = \tan^{-1}(b^*/a^*)$ and $C = (a^{*2} + b^{*2})^{1/2}$. Six measurements were performed for each potato sample.

2.4. Chemical analysis

2.4.1. Determination of starch profile

The enzymatic hydrolysis to D-glucose with the AOAC 996.11 (amyloglucosidase/α-amylase method) and AOAC 2002.02 methods, respectively (Megazyme, Ireland) were using for the total starch (TS) and resistant starch (RS) analysis The obtained D-(+)-glucose was oxidized which was quantitatively measured at $\lambda = 510$ nm. The TS and RS content were calculated as glucose × 0.9. The results are expressed as g kg^{-1} of the lyophilized weight (LW). Each sample was analyzed in triplicate.

2.4.2. Sample extraction of sugars, total phenolic and antioxidant capacity

Methanol extracts were prepared following the method proposed by Andre et al. (2009) with minor modifications. Briefly, 1 ± 0.001 g of the lyophilized powder was mixed with acidified methanol/water (80:20 v/v) and sonicated (Bandeline Sonoplus GM70, Germany) in an ice bath. After 15 min the sample was centrifuged (Selecta, Medifriger-BL, Spain) at 2313*g* at 4 °C. The supernatant was filtered (Whatman No.1 filter paper), and the pellet was re-extracted. The extracts were mixed and evaporated to dryness in a rotary evaporator at 40 °C (Laborata 4000 Efficient, Germany). The concentrate was diluted in acidified water (0.1 g L^{-1} HCl) and stored at −20 °C until further analysis. All samples were extracted in triplicate.

2.4.3. Determination of sugars by HPLC

The sugar contents were analyzed using a refraction index detector (Beckman Instruments, Inc., San Ramon, USA) with HPLC (HP1100, Hewlett–Packard, Santa Clara, USA) and a reverse phase-amide column (Phenomenex Luna column) according to the method of Rodriguez-Galdon, Rios, Rodriquez, and Diaz (2010). The individual sugars (glucose, fructose and sucrose) were identified and quantified by external calibration. Each extract was analyzed in triplicate, and the results are expressed as g kg^{-1} of LW.

2.4.4. Determination of total phenolic content

The total phenolic content (TPC) of potato skin and flesh extracts was assessed following to the Folin–Ciocalteu assay (Singleton, Orthofer, & Lamuela-Raventos, 1999). The absorbance was measured at $\lambda = 765$ nm in a Nicolet Evolution 300 Spectrophotometer (Thermo electron Corporation, Basingstoke, UK). Each extract was analyzed in triplicate, and the results are expressed in g gallic acid equivalent per kg^{-1} of LW (g GAE kg^{-1} LW).

2.4.5. Determination of total antioxidant activity

The antioxidant activity (AA) of the extracts of the potato flesh and skin was performed using the oxygen radical absorbance capacity (ORAC) assay, Gorjanovic et al. (2013). Approximately 15 μL of diluted sample or standard solutions (Trolox) was mixed with 150 μL of 9.57 × 10^{-2} μM fluorescein in a well plate and incubated at 37 °C for 10 min. The reactions were initiated by the addition of 50 μL of AAPH (2,2′-azobis (2-amidinopropane) dihydrochloride) solutions. The fluorescence was measured in a microplate fluorescence reader at 37 °C (Synergy™ Multi-detection Microplate Reader, BIO-TEK Instruments, USA) every 2 min for 120 min using excitation and emission wavelengths of 485 and 530 nm, respectively until the decay of the kinetic curve was complete. The area under the curve (AUC) was calculated for each sample, blank and standard. The reagents, standard and samples were prepared with phosphate buffer at a pH of 7.40. The results are expressed by g of Trolox equivalents (TE) per kg^{-1} of LW. Each extract was analyzed in triplicate.

2.5. Statistical analysis

All of the experiments were conducted in triplicate. The variation between the content of the potato components was evaluated using one-way analysis of variance (ANOVA) with Minitab 17 Statistical software (MINITAB Inc., State College, PA, USA). The differences between the mean values were evaluated using the HSD Tukey test with a 95% confidence interval. A principal component analysis (PCA) was conducted to illustrate the relationship between the variables and analyzed using STAT-ITCF statistical software (Bordeaux, France).

3. Results and discussion

3.1. Time–temperature profiles and cooking value of the heat-treatments

The starch gelatinization in potato tubers is dependent on the temperature evolution during the cooking process. Alvarez et al. (2001) studied the cooking of potatoes and found that at 60 °C the gelatinization process in the samples was very slow. At 70 °C, they found that the starch granule gelatinization was also partial, and between 82 °C and 90 °C, the potato starch completely gelatinized but only for a very short time. In our study, the temperature curves obtained for the different cultivars under the same treatment were very similar. However, the curves for the different cooking conditions were distinct, especially for microwaving, which is significantly different from baking and boiling (Fig. 1). Additionally, for microwaving, when the power was higher, there was less time needed to achieve the total gelatinization of the starch because of the quick increase in the core temperature. According to the cooking values (C_{100}, min) for the experiments, the related intensity of the cooking treatment is higher for microwaving (7.08–8.34 min) and baking (6.38–10.84 min), and followed by

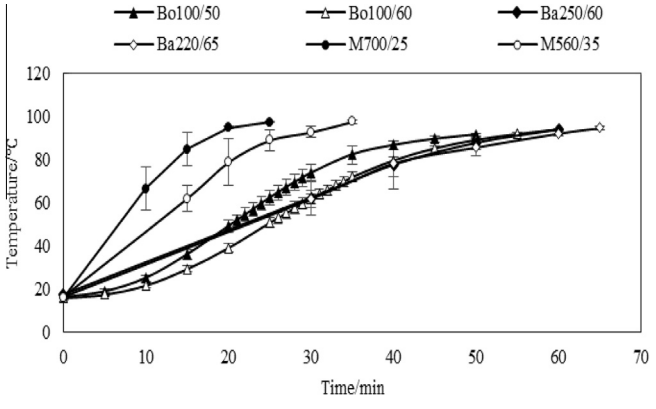

Fig. 1. Temperature curves of a typical potato cultivar (Kennebec) during boiling, baking and microwaving. Values are expressed as average ± standard deviations ($n = 3$).

boiling (4.11–6.17 min). For the microwaving treatment, there were no significant differences between cultivars at the two powers tested ($p < 0.05$).

3.2. Effect of cooking treatments on the physical properties

3.2.1. Weight loss and dry matter content

Depending on the treatment, the weight losses that were obtained were significantly different. Boiling produced the minimum values for all of the cultivars (<2%), whereas baking produced the highest losses (>20%). Błaszczak et al. (2004) studied the mechanical properties and microstructure of the potatoes after boiling and microwaving, and they concluded that the weigh losses obtained during microwaving (19–23%) were due to the presence of less hydrated and swollen starch granules that promote the evaporation of cellular water during microwave cooking. For our results, less losses were obtained after microwaving (<15%). In addition to the intensity of the treatment (C_{100}, min), the process time plays a key role in the weight loss when there is no water present during the cooking process. The possible differences in the microstructure of the potato peel may affect the water evaporation during the cooking procedures. The dry matter content of cv. Kennebec was significantly higher than in the other cultivars after processing (data not shown). However, the treatments affected the dry matter content of the potatoes in a similar way, which was independent of the initial value. For the four studied cultivars, baking and microwaving led to higher dry matter content, which is due to the water losses that occur during processing.

3.2.2. Texture parameters

The texture parameters of the fresh and cooked potatoes were evaluated. For the raw potatoes, the shear force of cv. Caesar was significantly higher than for cv. Red Pontiac (data not shown). Seefeldt, Tonning, Wiking, and Thybo (2011) stated that the changes in potato texture after cooking are related to the physicochemical properties and structure of the cell wall. The texture of cooked potatoes depends on the cooking conditions as a result of various factors, such as starch gelatinization, pectin degradation, cell wall breakdown, cell separation, etc. (Nourian, Ramaswamy, & Kushalappa, 2003). In our study, textural properties were directly affected by the cooking temperature and time. As expected, cooked samples had lower values compared with the raw potatoes. However, the softening of the potato tissues was significantly different between the cultivars. Additionally, when we analyzed the effect of the cooking conditions via the variance of the texture parameters, there were significant differences between the different treatments ($p < 0.05$), as shown in Fig. 2. The softness of cv. Agata was higher than the other cultivars; moreover, boiling and baking had a higher impact on the hardness and shear force. Hardness can be related to the force that is necessary to break the potato with the incisors during mastication (Garcia-Segovia, Andres-Bello, & Martinez-Monzo, 2008). For Kennebec, the higher hardness values were due to the higher dry matter content. For that cultivar, the longer boiling period ($Bo_{100/60}$) produces less hardness ($p < 0.05$). Alvarez and Canet (2001) reported that the harder product may be related to changes in the potato cell wall and middle lamella pectic material that occurs during the heat treatments. After microwaving ($M_{700/25}$ and $M_{560/35}$), the shear force of cv. Red Pontiac was significantly higher than for the other treatments. Chiavaro, Barbanti, Vittadini, and Massini (2006) suggested that the migration of water from the core of the potatoes slightly lowered the moisture availability in the potato tubers and limited the starch gelatinization. The diffusion of water during the cooking process may be responsible for the differences obtained for the different cooking temperatures. However, Garcia-Segovia et al. (2008) reported that the texture of cooked potatoes was directly associated with the dry matter content. Our results showed that a significant Pearson correlation coefficient was found between the dry matter and hardness ($r = 0.700$; $p < 0.001$; $n = 74$). The analyses of the variance of chewiness and springiness also revealed statistically significant differences between the heat treatments ($p < 0.05$). Boiling produced lower chewiness values in all potato cultivars because of the reduced intercellular adhesion that caused breaking of the potato structure (Chiavaro et al., 2006). The cohesiveness differences among the different heat treatments were not significant.

3.2.3. Color

The lightness (L^*), chroma (C^*) and hue (H^*) values varied considerably among the different raw potato cultivars (Table 1). The L^* values of fresh potato tubers increased from Agata (light yellow) to Kennebec (white) in the range of 51.14–65.50. The chroma values of the fresh potato cultivars were similar except for Red Pontiac, which had a lower value than the other cultivars ($p < 0.05$). The hue value was higher for Agata (light yellow), followed by Caesar (light yellow) and Red Pontiac (light yellow). The lowest hue value was obtained for Kennebec (white) among all of the fresh cultivars that we analyzed ($p < 0.05$).

After cooking, the L^* values decreased significantly except for Caesar ($p < 0.05$), in agreement with a previous study on carrots (Mazzeo et al., 2011), which suggests that as the potato samples became darker, the C^* values decreased. Additionally, the H^* values increased after the heat treatments of all of the cultivars in comparison with the raw potato samples (Table 1). After cooking, the darkening of the surface of the potatoes is attributed to a nonenzymatic reaction in which a colored chlorogenic acid-ferric iron complex is formed. Some authors have related the browning appearance to the lightness (L^*) measured on the surface of the potato (Lante & Zocca, 2010). Moreover, surprising results were found for the cv. Agata as compared with the values of different cultivars after the treatments: the L^* values were lower, and the C^* values were higher because of the lower and higher original value of L^* and C^*, respectively. Additionally, we found that the intensity of the treatment was not proportional to the color loss. Depending on the original color of the potato, the losses were different depending upon the different cooking treatment.

3.3. Effect of cooking treatments on chemical components

3.3.1. Starch profiles

The main constituents in potatoes are water and starch. The total starch content varies from 70% to 90% of the dry weight, depending on the botanical variety (Garcia-Alonso & Goni, 2000). The content of total starch (TS) and resistant starch (RS) in fresh potato cultivars ranged from 644.01 to 757.34 g kg^{-1} LW and from 467.80 to 599.66 g kg^{-1} LW (Red Pontiac < Agata < Kennebec < Caesar), respectively. The cooking treatments produced a new starch profile for all of the cultivars. Generally, the heat produced a significant reduction in the resistant starch (RS) content and an increase in the soluble starch content (Table 2). We observed that the average content of TS slightly decreased during boiling, baking and microwaving in the tested cultivars compared with the original value for the raw potatoes. The baked and microwaved potato samples had lower TS values than the boiled potatoes, possibly due to the difference in the gelatinization during baking and microwaving than during boiling.

When the potato tuber is cooked, almost all of the starch becomes digestible. However, different processing conditions and potato cultivars may affect the final RS content. The highest RS content percentage of the original value of the raw samples for an average of all of the cultivars was found in the baked potatoes. The variation of the average RS values for the potatoes under the

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

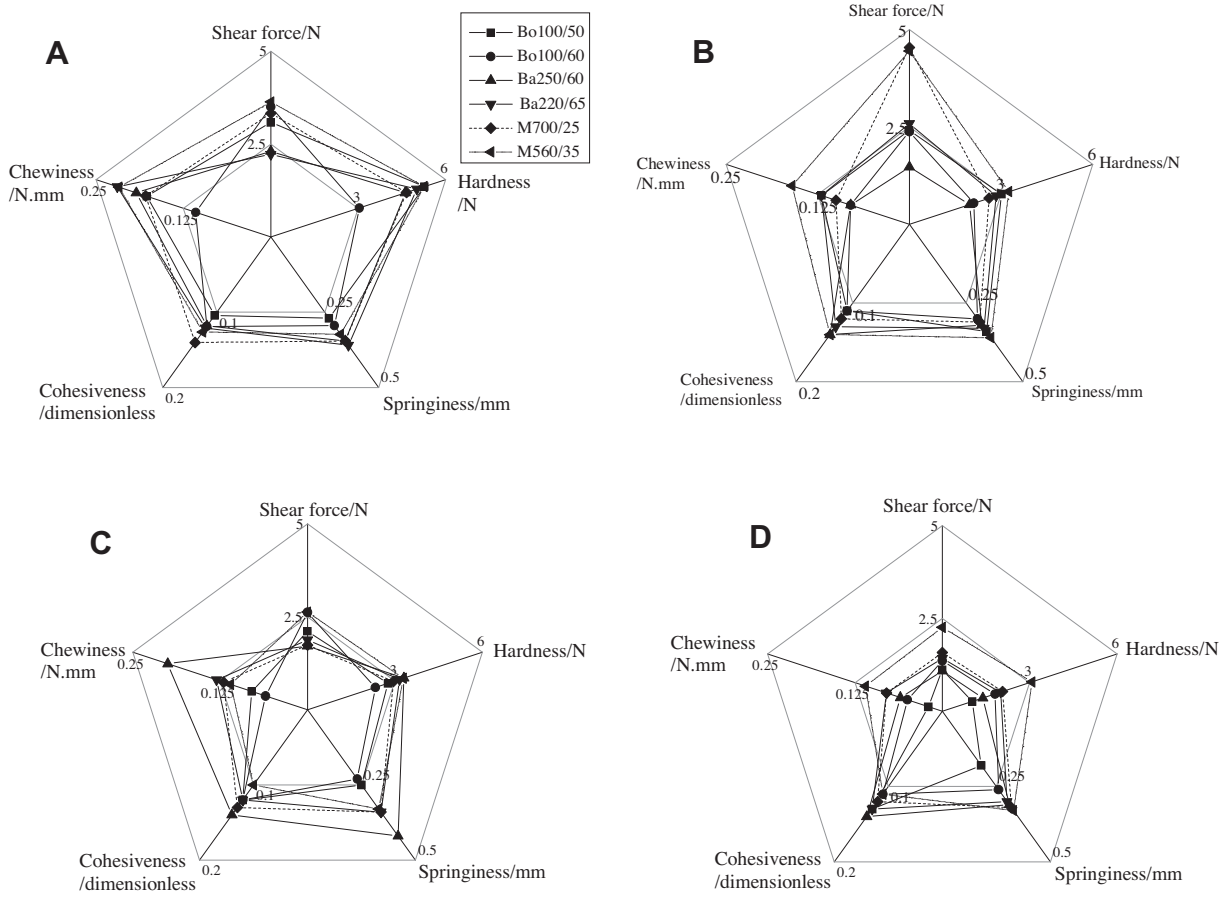

Fig. 2. Textural analysis parameters for different potato cultivars ((A) Kennebec; (B) Red Pontiac; (C) Caesar; (D) Agata) caused by different cooking treatments. Values are expressed as average ($n = 9$).

different conditions was insignificant. The higher RS content retention in the Kennebec and Agata cultivars was due to the baking treatment, while the higher RS retention of the Red Pontiac and Caesar cultivars was found in the microwaved potatoes. Therefore, the RS content retention for the baked and microwaved potatoes was higher than the retention of the boiled potatoes for all of the tested cultivars, which is in agreement with the report by Garcia-Alonso and Goni (2000). They found that the amount of RS depends on the degree of gelatinization and retrogradation during the cooling of the potato products. A positive and no significant correlation ($r = 0.171$, $p = 0.152$) was found between the cooking value and the RS content, which also verified the cooking quality of baking and microwaving over the quality of boiling.

3.3.2. Sugars

The sugar content of potatoes is in a form of a reducing monosaccharide, such as D-glucose and D-fructose, and a non-reducing disaccharide, such as sucrose (Lisinska & Leszczynski, 1989). The concentration of glucose (4.66–28.20 g kg^{-1} LW) was higher than that of fructose (5.35–25.81 g kg^{-1} LW) and sucrose (1.69–6.78 g kg^{-1} LW) in all of the fresh potato cultivars, which is in agreement with Plata-Guerrero, Hernandez, and Villanova (2009). The lowest sugar content (fructose, glucose and sucrose) (5.35, 4.66 and 1.69 g kg^{-1} LW, respectively) in all of the tested cultivars was cv. Kennebec. Our results showed that the reducing sugar (glucose and fructose) content of the fresh potato samples ranged from 10.01 to 53.46 g kg^{-1} LW, and cv. Red Pontiac and cv. Caesar tubers contained more reducing sugar content than those of the other cultivars ($p < 0.05$).

Significant changes in the glucose, fructose and sucrose content were observed during processing as several chemical reactions took place. One of the main reactions is the Maillard reaction in which the glucose and fructose react with amino acids to improve the sensory properties of the product, and the sucrose is hydrolyzed during the heat treatment (Murniece et al., 2011). The free starch can undergo degradation to form a monosaccharide, such as glucose, during processing.

We observe that the individual sugars (fructose, glucose and sucrose) increased during baking (5.07–38.37 g kg^{-1} LW) and microwaving (3.25–33.26 g kg^{-1} LW) compared with the raw tubers, and the highest increase was due to the baking treatment for all of cultivars, especially baking at 250 °C for 60 min ($B_{250/60}$). However, the sugar content of certain cultivars decreased during boiling, which may be due to the leaching of sugars in the water during processing. Significant differences between the cultivars were found ($p < 0.05$), e.g., the lowest sugar content (fructose, glucose and sucrose) in all of the cultivars after processing was cv. Kennebec due to the low original content.

3.3.3. Total phenolic content

The total phenolic content (TPC) of the fresh potatoes was analyzed for the four cultivars. The evaluation of the fresh potatoes for TPC revealed that there was a higher phenolic concentration in the skin than in the flesh, and it was often two-times more. The TPC of the potato flesh and skin ranged from 1.05 (Agata) to 2.49 (Caesar) g GAE kg^{-1} LW and from 2.89 (Kennebec) to 4.40 (Red Pontiac) g GAE kg^{-1} LW, respectively. The TPC of the skin of the cv. Red Pontiac was higher than for the other cultivars because of its red skin color.

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

Table 1
Colour parameters of raw and cooked potato samples.

Cultivar	Treatments	L^*	C^*	H^* (°)
Kennebec	Raw	65.50 ± 1.78a	12.04 ± 0.38a	100.08 ± 0.61c
Red Pontiac	Raw	60.74 ± 1.45b	8.21 ± 0.28b	100.60 ± 1.22bc
Caesar	Raw	53.18 ± 1.89c	12.31 ± 0.88a	101.78 ± 0.90b
Agata	Raw	51.14 ± 1.28c	12.26 ± 0.90a	103.34 ± 0.22a
Kennebec	$Bo_{100/50}$	58.91 ± 2.98a	6.11 ± 0.19a	134.79 ± 1.08a
	$Bo_{100/60}$	60.42 ± 1.80a	6.08 ± 0.42a	135.30 ± 9.50a
	$Ba_{250/60}$	57.90 ± 1.61a	6.20 ± 0.35a	135.21 ± 0.62a
	$Ba_{220/60}$	59.16 ± 0.93a	6.10 ± 0.36a	135.99 ± 0.69a
	$M_{700/25}$	60.52 ± 0.97a	5.29 ± 0.39ab	139.73 ± 4.16a
	$M_{560/35}$	57.57 ± 0.89a	4.90 ± 0.44b	145.03 ± 6.36a
Red Pontiac	$Bo_{100/50}$	50.59 ± 0.34c	4.46 ± 0.23ab	143.67 ± 10.94ab
	$Bo_{100/60}$	52.23 ± 1.07c	3.98 ± 0.17b	157.31 ± 7.18a
	$Ba_{250/60}$	52.17 ± 2.61c	5.13 ± 0.35a	139.50 ± 3.89b
	$Ba_{220/60}$	53.53 ± 1.94bc	4.09 ± 0.19b	151.00 ± 3.25ab
	$M_{700/25}$	59.29 ± 2.60a	5.09 ± 0.28a	142.38 ± 1.27ab
	$M_{560/35}$	58.36 ± 2.27ab	5.14 ± 0.36a	142.88 ± 2.03ab
Caesar	$Bo_{100/50}$	56.49 ± 1.92a	7.71 ± 1.08a	137.06 ± 4.92ab
	$Bo_{100/60}$	54.40 ± 2.22a	7.63 ± 0.67a	134.58 ± 3.78ab
	$Ba_{250/60}$	58.42 ± 0.98a	5.81 ± 0.78a	142.33 ± 3.78a
	$Ba_{220/60}$	57.96 ± 0.97a	7.38 ± 0.63a	135.70 ± 2.89ab
	$M_{700/25}$	57.42 ± 1.97a	8.03 ± 0.44a	131.73 ± 2.51b
	$M_{560/35}$	56.56 ± 1.60a	7.66 ± 1.32a	132.57 ± 4.90ab
Agata	$Bo_{100/50}$	44.03 ± 2.69a	8.46 ± 0.75a	119.64 ± 1.90a
	$Bo_{100/60}$	44.02 ± 0.52a	9.11 ± 0.63a	118.72 ± 0.62a
	$Ba_{250/60}$	44.08 ± 1.62a	8.55 ± 0.88a	116.95 ± 6.02a
	$Ba_{220/60}$	44.54 ± 2.04a	8.25 ± 0.35a	121.67 ± 2.60a
	$M_{700/25}$	45.61 ± 3.07a	7.89 ± 0.40a	121.37 ± 1.63a
	$M_{560/35}$	44.21 ± 1.15a	8.32 ± 1.24a	120.00 ± 3.18a

Values are expressed as mean values ± standard deviations.
One-way balance ANOVA was performed for each potato cultivar.
Mean values with different small letters are significant in columns ($p < 0.05$).

Several authors have described a considerable reduction in the amount of TPC during cooking, depending on the cultivar and cooking methods (Blessington et al., 2010; Perla et al., 2012). We observed that the changes in the TPC of the potato flesh were more dependent on the genotype of each cultivar (Table 3). After cooking, the TPC of cv. Caesar and cv. Agata significantly differed from the other cultivars because of their lowest and highest retentions of TPC, respectively. For the boiling treatment, the TPC retention of $Bo_{100/60}$ in the three cultivars (Red Pontiac, Caesar and Agata) were slightly higher than the content after $Bo_{100/50}$, which suggests that the lower core temperature assisted in retaining the TPC. The TPC retention percentage after baking, $Ba_{250/60}$, was higher than $Ba_{220/65}$ in all of the tested cultivars except for Kennebec. For the baked potatoes, the highest temperature and the shortest time retained higher levels of TPC in all three of the potato cultivars. Navarre et al. (2010) stated that baking at 375 °C for 30 min increases the amount of extractable phenolics, while Perla et al. (2012) found a 54.0% loss in the TPC after baking at 204 °C for 60 min. Additionally, the TPC retention values after microwaving, $M_{560/35}$, were higher than $M_{700/25}$, which indicates that the lower power plays a key role in retaining a higher TPC content for the microwaved potatoes. In summary, a lower core temperature during boiling, a higher temperature and shorter baking time, and a lower microwave power were all beneficial for retaining the TPC in the potato flesh of the cultivars. Palermo, Pellegrini, and Fogliano (2014) suggested that the reduction of TPC after the cooking treatments was attributed to water-soluble phenolics that leach into the water (boiling) and breakdown. Therefore, the phenolic compounds are highly reactive species that undergo several reactions during food processing that are related to the cultivars and cooking conditions.

The removal of the skin before or after cooking is influential in determining the phenolic compounds (Blessington et al., 2010). Recently, there have been some controversial results on the effect of different heat treatments on the TPC levels. Mattila and Hellstrom (2007) observed that the cooked potato peels exhibited enhanced the TPC levels when compared to uncooked peels. In contrast, Mondy and Gosselin (1988) suggested that during processing the phenolic compounds migrated from the peel into both the cortex and the internal tissues of the potato tubers, leading to the decrease in the peel content. Our results suggest that higher losses of TPC in the potato skin were obtained after boiling and microwaving; however, the TPC slightly increased after baking for all of the cultivars (Table 3).

3.3.4. Antioxidant activity

The different heat treatments reduced or, in some cases, enhanced the antioxidant activity (AA) of the potato genotypes with respect to the uncooked potato samples (Blessington et al., 2010; Navarre et al., 2010; Perla et al., 2012). The AA in the flesh of the raw potato samples ranged from 9.93 (Agata) to 26.46 (Caesar) g TE kg^{-1} LW, and the AA in the skin of the raw potatoes ranged from 60.59 (Caesar) to 97.56 (Agata) g TE kg^{-1} LW.

The average AA content in the flesh samples increased after all of the cooking methods when compared with the uncooked potato samples, which is in agreement with Blessington et al. (2010) and Navarre et al. (2010). However, the largest increase was caused by the microwave treatment. The AA increase in potato fleshes may be associated with an increase in the extractability of these compounds from the cellular matrix due to the starch textural changes during the cooking processes (Blessington et al., 2010). Additionally, cooking may result in higher recoveries and produce inactivating enzymes that consume the AA during the processing (Navarre et al., 2010). Although a consistent trend for the AA in the overall average results for all of the cultivars was found, the differences between the cultivars and the heat treatments were inconclusive

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

Table 2
Starch content in raw and cooked potatoes.

Cultivar	Treatments	Starch content (g kg^{-1} DW)		Ratio RS after cooking versus raw material (%)
		Total starch	Resistant starch	
Kennebec	Raw	693.0 ± 24.3b	574.5 ± 18.1ab	–
Red Pontiac	Raw	644.0 ± 7.1c	467.8 ± 20.5c	–
Caesar	Raw	757.3 ± 19.5a	599.7 ± 30.5a	–
Agata	Raw	680.3 ± 16.0bc	544.6 ± 7.9b	–
Kennebec	$Bo_{100/50}$	696.3 ± 9.2a	22.4 ± 0.7b	3.9
	$Bo_{100/60}$	705.7 ± 15.2a	25.5 ± 1.1ab	4.4
	$Ba_{250/60}$	694.1 ± 5.8a	27.5 ± 1.9a	4.8
	$Ba_{220/60}$	653.9 ± 6.7b	25.1 ± 0.7ab	4.4
	$M_{700/25}$	615.2 ± 9.2c	23.0 ± 1.8b	4.0
	$M_{560/35}$	614.0 ± 9.2c	24.6 ± 2.2ab	4.3
Red Pontiac	$Bo_{100/50}$	679.0 ± 6.5a	24.5 ± 1.3a	5.2
	$Bo_{100/60}$	673.5 ± 7.8a	25.3 ± 1.1a	5.4
	$Ba_{250/60}$	616.5 ± 21.5b	26.1 ± 2.5a	5.6
	$Ba_{220/60}$	637.7 ± 13.3ab	27.0 ± 2.0a	5.8
	$M_{700/25}$	666.6 ± 31.3a	27.9 ± 1.5a	6.0
	$M_{560/35}$	651.4 ± 8.4ab	26.8 ± 3.1a	5.7
Caesar	$Bo_{100/50}$	712.9 ± 24.9a	29.0 ± 1.1a	4.8
	$Bo_{100/60}$	704.5 ± 15.3ab	29.3 ± 2.1a	4.9
	$Ba_{250/60}$	653.9 ± 15.0bc	29.7 ± 0.7a	5.0
	$Ba_{220/60}$	67.18 ± 11.6abc	32.0 ± 1.9a	5.3
	$M_{700/25}$	624.6 ± 23.2c	33.1 ± 2.5a	5.5
	$M_{560/35}$	656.9 ± 22.1bc	32.8 ± 1.2a	5.5
Agata	$Bo_{100/50}$	619.5 ± 16.9b	30.7 ± 2.1ab	5.6
	$Bo_{100/60}$	654.5 ± 26.3ab	32.0 ± 2.1a	5.9
	$Ba_{250/60}$	669.7 ± 3.1ab	33.7 ± 1.9a	6.2
	$Ba_{220/60}$	676.8 ± 24.3a	29.9 ± 2.5ab	5.5
	$M_{700/25}$	613.7 ± 22.7b	25.4 ± 2.9b	4.7
	$M_{560/35}$	624.2 ± 35.9b	25.8 ± 0.9b	4.7

Values are expressed as mean values ± standard deviations.
One-way balance ANOVA was performed for each potato cultivar.
Mean values with different small letters are significant in columns ($p < 0.05$).

Table 3
Total phenolic content (g GAE kg^{-1} LW) and antioxidant activity (g TE kg^{-1} LW) in raw and cooked potatoes.

Cultivar	Raw	$Bo_{100/50}$	$Bo_{100/60}$	$Ba_{250/60}$	$Ba_{220/65}$	$M_{700/25}$	$M_{560//35}$
Total phenolic compounds – flesh							
Kennebec	1.15 ± 0.07^{bc,A}	1.33 ± 0.12^{bc,ABC}	1.07 ± 0.05^{b,AB}	0.64 ± 0.07^{d,D}	0.89 ± 0.13^{bc,BC}	1.10 ± 0.06^{ab,AB}	0.80 ± 0.04^{b,CD}
Red Pontiac	1.28 ± 0.07^{b,B}	0.98 ± 0.09^{b,C}	1.03 ± 0.04^{b,C}	1.54 ± 0.12^{b,A}	1.52 ± 0.01^{a,A}	0.94 ± 0.12^{bc,C}	1.15 ± 0.09^{ab,BC}
Caesar	2.49 ± 0.34^{a,A}	0.74 ± 0.09^{c,B}	1.17 ± 0.15^{b,B}	0.89 ± 0.04^{c,B}	0.69 ± 0.03^{c,B}	0.74 ± 0.09^{c,B}	0.89 ± 0.06^{b,B}
Agata	1.05 ± 0.13^{c,E}	1.53 ± 0.06^{a,ABC}	1.63 ± 0.15^{a,AB}	1.82 ± 0.11^{a,A}	1.01 ± 0.11^{b,D}	1.31 ± 0.06^{a,CD}	1.37 ± 0.12^{a,BC}
Total phenolic compounds – skin							
Kennebec	2.89 ± 0.29^{c,AB}	2.46 ± 0.14^{bc,BC}	2.40 ± 0.25^{bc,BC}	2.35 ± 0.17^{c,BC}	3.32 ± 0.39^{a,A}	1.95 ± 0.15^{b,C}	1.83 ± 0.21^{c,C}
Red Pontiac	4.40 ± 0.17^{a,B}	3.27 ± 0.20^{a,C}	3.38 ± 0.29^{a,C}	5.26 ± 0.41^{a,A}	4.19 ± 0.08^{a,B}	3.23 ± 0.33^{a,C}	2.75 ± 0.16^{b,C}
Caesar	3.65 ± 0.36^{b,A}	2.04 ± 0.11^{c,B}	2.01 ± 0.28^{c,B}	3.55 ± 0.15^{b,A}	3.80 ± 0.30^{a,A}	1.86 ± 0.12^{b,B}	1.76 ± 0.25^{c,B}
Agata	4.3 ± 0.25^{ab,AB}	2.67 ± 0.25^{b,D}	3.20 ± 0.28^{ab,BCD}	4.74 ± 0.67^{a,A}	3.97 ± 0.45^{a,ABC}	3.15 ± 0.12^{a,CD}	3.35 ± 0.25^{a,BCD}
Antioxidant activity – flesh							
Kennebec	11.10 ± 0.82^{c,B}	14.05 ± 1.35^{b,AB}	18.24 ± 1.33^{a,A}	9.90 ± 0.61^{b,B}	11.89 ± 1.66^{b,B}	16.87 ± 1.69^{ab,A}	14.22 ± 1.25^{a,AB}
Red Pontiac	15.10 ± 0.89^{b,AB}	14.32 ± 0.76^{ab,AB}	14.48 ± 1.64^{ab,AB}	18.35 ± 0.80^{a,A}	12.58 ± 1.23^{b,B}	16.04 ± 0.72^{b,AB}	18.09 ± 1.60^{a,A}
Caesar	26.46 ± 0.51^{a,A}	10.06 ± 1.40^{c,BC}	11.04 ± 1.14^{b,BC}	8.42 ± 1.22^{b,C}	8.59 ± 1.47^{b,C}	9.12 ± 0.96^{c,BC}	13.45 ± 1.02^{a,B}
Agata	9.93 ± 1.02^{d,B}	17.47 ± 1.32^{a,A}	17.47 ± 1.57^{a,A}	19.91 ± 3.15^{a,A}	19.15 ± 1.98^{a,A}	21.35 ± 2.13^{a,A}	17.29 ± 1.30^{a,A}
Antioxidant activity – skin							
Kennebec	76.14 ± 1.05^{ab,A}	32.98 ± 3.41^{c,C}	48.25 ± 2.30^{b,B}	52.76 ± 1.68^{b,B}	74.97 ± 2.91^{ab,A}	31.95 ± 4.24^{b,C}	35.39 ± 4.79^{b,C}
Red Pontiac	88.26 ± 4.53^{a,A}	80.68 ± 5.18^{a,A}	77.13 ± 4.91^{a,A}	83.18 ± 3.38^{a,A}	54.63 ± 4.67^{b,A}	84.20 ± 6.70^{a,A}	72.41 ± 6.21^{a,A}
Caesar	60.59 ± 3.87^{b,A}	52.63 ± 3.25^{b,AB}	51.62 ± 2.52^{b,AB}	58.34 ± 3.81^{ab,A}	55.76 ± 4.91^{ab,AB}	34.37 ± 4.28^{b,B}	33.36 ± 1.38^{b,B}
Agata	97.56 ± 4.04^{a,A}	59.76 ± 4.40^{b,B}	68.17 ± 3.92^{a,B}	74.47 ± 4.48^{ab,B}	77.83 ± 3.41^{a,AB}	68.09 ± 2.96^{a,B}	62.72 ± 1.52^{a,B}

Values are expressed as mean values ± standard deviations.
One-way balance ANOVA by Tukey's test was performed.
The mean values with different small letters are significant in columns and the means values with different capitals are significant in rows ($p < 0.05$).

due to the large internal variability of the cultivars and the different cooking conditions. The cultivars exhibited a more considerable influence on the AA changes in the flesh of the potato samples (Table 3). The cv. Agata showed a significant increase in the AA of the flesh samples (increased to 174–215% of the original value). In contrast, the cv. Caesar showed a significant reduction in the AA (to 38–51% of original value) when compared with the other cultivars.

Potato tubers are always cooked before consumption; however, there is very limited information on the effect of cooking on the AA of cultivars in the flesh and skin, especially in the skin. All of the cooking methods demonstrated a reduced AA in the potato peels

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

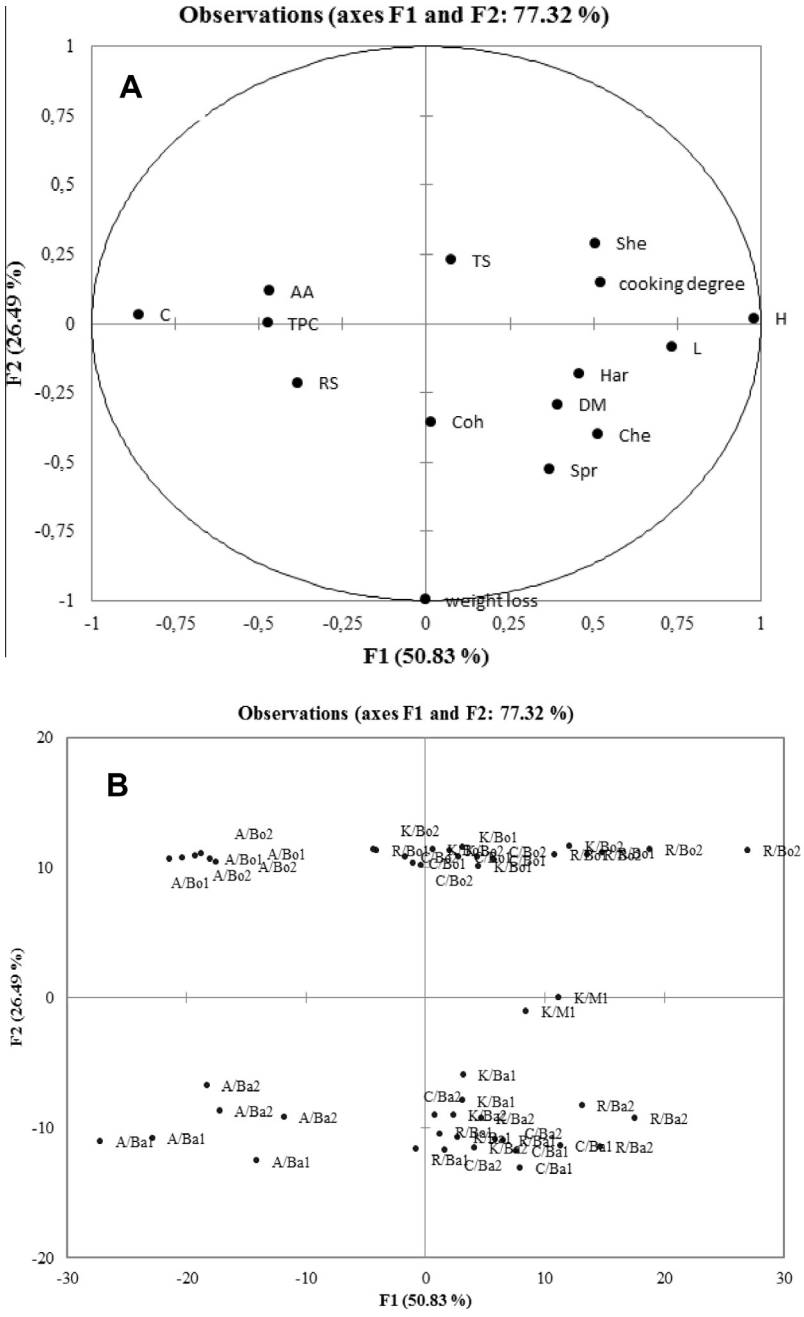

Fig. 3. Principal component analysis (PCA) of physical and chemical properties of cooked potatoes. (A) DM = dry matter, TS = total starch, RS = resistant starch, TPC = total phenolic content, AA = antioxidant activity, She = shear force, Har = hardness, Spr = springiness, Coh = cohesiveness, Che = chewiness, *C* = chroma, *H* = hue angle, *L* = lightness. (B) K: Kennebec; R: Red Pontiac; C: Caesar; A: Agata. Bo1: $Bo_{100/50}$; Bo2: $Bo_{100/60}$; Ba1: $Ba_{250/60}$; Ba2: $Ba_{220/65}$; M1: $M_{700/25}$; M2: $M_{560/35}$.

in comparison with the uncooked potato peels (Table 3) The most favorable influence on the content of AA in the peels was achieved via baking, except for with the Red Pontiac at $Ba_{250/60}$. If potatoes are eaten with their skin, some nutrient losses are avoided.

3.4. Principle component analysis

Principle component analysis (PCA) was used to summarize the relationship between the properties of the potato cultivars that were tested after cooking with the different heat treatments. The PCA reduced the number of variables in the physical and chemical properties of the potatoes to simplify the data without loss of relevant information and to improve the understanding of the associations via identification of new, uncorrelated variables (Alvarez & Canet, 2001).

The PCA revealed that fifteen principle components (F1–F15) explained the variance among the data, and the first two principle components accounted for 77.32% of the total variation (Fig. 3A). The first component (F1) explained 50.83% of the total variance, and the second component (F2) accounted for 26.49% of the total variance, which indicated that the first two principal components included variables that differentiated the tested cultivars. The texture parameters (shear force, hardness and chewiness), color parameters (hue angle and lightness) and cooking degrees had positive loadings, and the RS, AA and chroma had negative loadings for the first principal component. The weight loss, springiness, cohesiveness and DM had negative loadings, while the TS and

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028

TPC had positive loadings for the second principal component. The properties of the potatoes showed similar directions, indicating a strong relationship between these attributes.

After six different processing treatments, four cultivars were scattered, and different groups were observed for the F1 and F2 and are shown in Fig. 3B. However, the scores of samples after microwaving, except for the Kennebec cultivar, are not shown in Fig. 3B because the scores of the vectors were too close to the zero line. The directions of F1 explained the effect of the cultivars on the properties of the potatoes, whereas F2 explained the effect of the heat treatments on the properties. Regarding F2 for the tested cultivars after different heat treatments, after boiling, all of the tested cultivars were associated with the highest TS and TPC. After baking, the tubers exhibited higher DM, springiness, cohesiveness and weight loss. However, the cultivars that were microwaved could be classified into two groups: (1) the Kennebec and Red Pontiac cultivars exhibited the highest shear force, hardness, chewiness, *H*, *L* and cooking degree, (2) the Caesar and Agata cultivar exhibited the highest RS, AA and C. F1 primarily discriminated the cooked potato cultivars: the Agata cultivars from the Kennebec, Red Pontiac and Caesar cultivars. After the heat treatments, the Agata cultivar exhibited higher AA, TPC, RS and C, and the other cultivars (Kennebec, Red Pontiac and Caesar) were associated with the higher TS, DM, cooking degree, the textural parameter values and the color parameter (*L* and *H*) values.

The PCA was sufficient to prove the effect of the different treatments and the different cultivars on the properties of the potatoes. However, the cultivars with higher color parameter values (*L* and *H*) and the higher textural parameter values were associated with more DM and TS content, while the cultivars with higher TPC, AA and RS content were related to the higher color parameter value (*L*). Additionally, the cultivars after boiling exhibited higher TS and TPC, while the tubers after baking showed DM and weight loss. Therefore, the PCA results verified that there were significant relationships between the physical instrumental properties and the functional properties after cooking. According to the PCA, the physical instrumental properties can be considered as an indicator of some of the nutritional and functional properties of cooked potato products, which can establish the nutritional difference and may be useful in industry. Moreover, some of the nutritional and functional parameters of the different cultivars after the treatments demonstrated the potential efficacy of processing potatoes to satisfy the nutritional needs of consumers and industry.

4. Conclusions

The effect of cooking treatments and cultivars on the physical and chemical properties of potatoes was investigated. Cooking treatments with air produced higher weight losses because of the evaporation of water across the skin, which was independent of the cultivar. Baking promoted the higher losses than microwaving. The softening after cooking depended on the potato cultivar. The softness of cv. Agata was higher than the other cultivars. Boiling and baking highly affected the shear force and hardness. However, the chewiness and springiness were remarkably different between the treatments for all potato cultivars. The diffusion of water across the potato tissues may be responsible for the differences in softening. All of the cooking treatments affected the dry matter independent of the assessed potato cultivar. Microwaved potatoes exhibited higher values of DM. The intensity of the treatment was not proportional to the color losses after cooking.

Less time is needed for the starch gelatinization of potatoes during microwaving than with boiling and baking under the studied conditions. The TS and RS decreased after processing, and the RS retention due to baking and microwaving was higher than when the potatoes were boiled. The individual sugars (fructose, glucose and sucrose) increased during baking and microwaving, but the content of certain cultivars decreased during boiling.

The effect of the cooking process on the TPC and AA in potato flesh depends on the potato cultivar. However, the maximum retention of bioactive compounds was obtained when there was a lower core temperature during boiling, for the higher temperature and shorter baking times, and for microwaving on low power.

Regarding the different cultivars and heat treatments, the PCA results demonstrated a significant relationship between the instrumental properties and functional properties after cooking the potato cultivars. The physical instrumental properties may be the indicator of some nutritional and functional properties of cooked potato products. Certain nutritional and functional parameters of different cultivars after the treatments indicated the potential efficacy to satisfy the nutritional needs of consumers and the potential to satisfy the requirements for industry use.

Acknowledgment

This work was supported in part by the China Scholarship Council (File No. 201206990014).

References

Alvarez, M. D., & Canet, W. (2001). Principal component analysis to study the effect of temperature fluctuations during storage of frozen potato. *European Food Research and Technology, 211*(6), 415–421.

Alvarez, M. D., Canet, W., & Tortosa, M. E. (2001). Kinetics of thermal softening of potato tissue (cv. Monalisa) by water heating. *European Food Research and Technology, 212*(5), 588–596.

Andre, C. M., Oufir, M., Hoffmann, L., Hausman, J. F., Rogez, H., Larondelle, Y., & Evers, D. (2009). Influence of environment and genotype on polyphenol compounds and in vitro antioxidant capacity of native Andean potatoes (*Solanum tuberosum* L.). *Journal of Food Composition and Analysis, 22*(6), 517–524.

Barba, A. A., Calabretti, A., Amore, M., Piccinelli, A. L., & Rastrelli, L. (2008). Phenolic constituents levels in cv. Agria potato under microwave processing. *Food Science and Technology, 41*(10), 1919–1926.

Błaszczak, W., Sadowska, J., Fornal, J., Vacek, J., Flis, B., & Zagórski-Ostoja, W. (2004). Influence of cooking and microwave heating on microstructure and mechanical properties of transgenic potatoes. *Nahrung/Food, 48*(3), 169–176.

Blessington, T., Nzaramba, M. N., Scheuring, D. C., Hale, A. L., Reddivari, L., & Miller, J. C. (2010). Cooking methods and storage treatments of potato: Effects on carotenoids, antioxidant activity, and phenolics. *American of Journal of Potato Research, 87*(6), 479–491.

Bordoloi, A., Kaur, L., & Singh, J. (2012). Parenchyma cell microstructure and textural characteristics of raw and cooked potatoes. *Food Chemistry, 133*(4), 1092–1100.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology, 32*, 62–66.

Bourne, M. C. (1989). Applications of chemical kinetic theory to the rate of thermal softening of vegetable tissue. In J. J. Jen (Ed.), *Quality factors of fruits and vegetables* (pp. 98–110). Chemistry and Technology.

Chiavaro, E., Barbanti, D., Vittadini, E., & Massini, R. (2006). The effect of different cooking methods on the instrumental quality of potatoes (cv. Agata). *Journal of Food Engineering, 77*(1), 169–178.

Chuah, A. M., Lee, Y. C., Yamaguchi, T., Takamura, H., Yin, L. J., & Matoba, T. (2008). Effect of cooking on the antioxidant properties of coloured peppers. *Food Chemistry, 111*(1), 20–28.

Friedman, M. (1997). Chemistry, biochemistry, and dietary role of potato polyphenols. A review. *Journal of Agriculture and Food Chemistry, 45*(5), 1523–1540.

Garcia-Alonso, A., & Goni, I. (2000). Effect of processing on potato starch: In vitro availability and glycaemic index. *Starch/Starke, 52*(2–3), 81–84.

Garcia-Segovia, P., Andres-Bello, A., & Martinez-Monzo, J. (2008). Textural properties of potatoes (*Solanum tuberosum* L., cv. Monalisa) as affected by different cooking processes. *Journal of Food Engineering, 88*(1), 28–35.

Gorjanovic, S. Z., Alvarez-Suarez, J. M., Novakovic, M. M., Pastor, F. T., Pezo, L., Battino, M., & Suznjevic, D. Z. (2013). Comparative analysis of antioxidant activity of honey of different floral sources using recently developed polarographic and various spectrophotometric assays. *Journal of Food Composition and Analysis, 1*(30), 13–18.

Kaur, L., Singh, N., Sodhi, N. S., & Gujral, H. S. (2002). Some properties of potatoes and their starches. Cooking, textural and rheological properties of potatoes. *Food Chemistry, 79*(2), 177–181.

Lachman, J., Hamouz, K., Musilova, J., Hejtmankova, K., Kotikova, Z., Pazderu, K., ... Cimr, J. (2013). Effect of peeling and three cooking methods on the content of selected phytochemicals in potato tubers with various colour of flesh. *Food Chemistry, 138*(2–3), 1189–1197.

Lante, A., & Zocca, F. (2010). Effect of β-cyclodextrin addition on quality of precooked vacuum packed potatoes. *Food Science and Technology, 43*(3), 409–414.

Ling, B., Tang, J., Kong, F., Mitcham, E. J., & Wang, S. (2015). Kinetics of food quality changes during thermal processing: A review. *Food and Bioprocess Technology, 8*(2), 343–358.

Lisinska, G., & Leszczynski, W. (1989). *Potato science and technology*. London and New York: Elsevier Applied Science (pp. 1–140).

Liu, Q., Tarn, R., Lynch, D., & Skjodt, N. M. (2007). Physicochemical properties of dry matter and starch from potatoes grown in Canada. *Food Chemistry, 105*(3), 897–907.

Mattila, P., & Hellstrom, J. (2007). Phenolic acids in potatoes, vegetables, and some of their products. *Journal of Food Composition and Analysis, 20*(3–4), 152–160.

Mazzeo, T., N'Dri, D., Chiavaro, E., Visconti, A., Fogliano, V., & Pellegrini, N. (2011). Effect of two cooking procedures on phytochemical compounds, total antioxidant capacity and colour of selected frozen vegetables. *Food Chemistry, 128*(3), 627–633.

Mondy, N. I., & Gosselin, B. (1988). Effect of peeling on total phenols, total glycoalkaloids, discoloration and flavor of cooked potatoes. *Journal of Food Science, 53*(3), 756–759.

Mulinacci, N., Leri, F., Giaccherini, C., Innocenti, M., Andrenelli, L., Canova, G., ... Casiraghi, M. C. (2008). Effect of cooking on the anthocyanins, phenolic acids, glycoalkaloids, and resistant starch content in two pigmented cultivars of *Solanum tuberosum* L.. *Journal of Agricultural and Food Chemistry, 56*(24), 11830–11837.

Murniece, I., Karklina, D., Galoburda, R., Santare, D., Skrabule, I., & Costa, H. S. (2011). Nutritional composition of freshly harvested and stored Latvian potato (*Solanum tuberosum* L.) varieties depending on traditional cooking methods. *Journal of Food Composition and Analysis, 24*(4–5), 699–710.

Navarre, D. A., Shakya, R., Holden, J., & Kumar, S. (2010). The effect of different cooking methods on phenolics and vitamin C in developmentally young potato tubers. *American Journal of Potato Research, 87*(4), 350–359.

Nourian, F., Ramaswamy, H. S., & Kushalappa, A. C. (2003). Kinetic changes in cooking quality of potatoes stored at different temperatures. *Journal of Food Engineering, 60*(3), 257–266.

Palermo, M., Pellegrini, N., & Fogliano, V. (2014). The effect of cooking on the phytochemical content of vegetables. *Journal of the Science of Food and Agriculture, 94*(6), 1057–1070.

Perla, V., Holm, D. G., & Jayanty, S. S. (2012). Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. *Food Science and Technology, 45*(2), 161–171.

Plata-Guerrero, P. R., Hernandez, G. E., & Villanova, G. B. (2009). Determination of reducing sugars and asparagine in potatoes. *Journal of Liquid Chromatography and Related Technologies, 32*(17), 2556–2568.

Price, K. R., Bacon, J. R., & Rhodes, M. J. C. (1997). Effect of storage and domestic processing on the content and composition of flavonol glucosides in onion (*Allium cepa*). *Journal of Agricultural and Food Chemistry, 45*(3), 938–942.

Rodriguez-Galdon, B., Rios, M. D., Rodriquez, E. M., & Diaz, R. C. (2010). Influence of the cultivar on the organic acid and sugar composition of potatoes. *Journal of the Science of Food and Agriculture, 90*(13), 2301–2309.

Rumbaoa, R., Cornago, D., & Geronimo, I. (2009). Phenolic content and antioxidant capacity of Philippine potato (*Solanum tuberosum*) tubers. *Food Composition and Analysis, 22*(6), 546–550.

Seefeldt, H. F., Tonning, E., Wiking, L., & Thybo, A. K. (2011). Appropriateness of culinary preparations of potato (*Solanum tuberosum* L.) varieties and relation to sensory and physicochemical properties. *Journal of Agricultural and Food Science, 91*(3), 412–420.

Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteu reagent. *Methods in Enzymology, 299*, 152–178.

Stushnoff, C., Holim, D., Thompson, M. D., Jiang, W., Thompson, H. J., Joyce, N. I., & Wilson, P. (2008). Antioxidant properties of cultivars and selections from the Colorado Potato Breeding Program. *American Journal of Potato Research, 85*(4), 267–276.

Turkmen, N., Poyrazoglu, E. S., Sari, F., & Velioglu, S. Y. (2006). Effects of cooking methods on chlorophylls, pheophytins and colour of selected green vegetables. *International Journal of Food Science and Technology, 41*(3), 281–288.

Waldron, K. W., Smith, A. C., Parr, A. J., Ng, A., & Parker, M. L. (1997). New approaches to understanding and controlling cell separation in relation to fruit and vegetable texture. *Trends in Food Science and Technology, 8*(7), 213–221.

Yadav, B. S. (2011). Effect of frying, baking and storage conditions on the resistant starch content of foods. *British Food Journal, 113*(6), 710–718.

Yang, Y., Achaerandio, I., & Pujolà, M. (2015). Classification of potato cultivars to establish their processing aptitude. *Journal Science of Food Agriculture*. http://dx.doi.org/10.1002/jsfa.7104.

Please cite this article in press as: Yang, Y., et al. Effect of the intensity of cooking methods on the nutritional and physical properties of potato tubers. *Food Chemistry* (2015), http://dx.doi.org/10.1016/j.foodchem.2015.11.028