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Full Length Research Paper

## Changes in the quality characteristics of the butter of *Pentadesma butyracea* under various storage conditions

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The aim of this study was to identify the storage conditions that warrant the optimum quality of the butter of *P. butyracea*. An experimental design was set up to study the effects of kernel boiling, the packaging material and the storage duration on the colour, saponification value and unsaponifiable fractions, acid and peroxide values and the iodine index of the butter of *P. butyracea*. The quality parameters of the butter vary significantly according to the storage conditions of the kernels. For all samples, the acid value increased significantly during the storage varying from 0.08 to 0.99 mg KOH/g and from 0.08 to 0.91 mg KOH/g for the kernels boiled and dried and for the kernels dried directly without boiling respectively. The peroxide value of the butter remains quite stable during the first 6 months of storage. The most significant modification occur between 6 and 12 months where an increasing from 3.82 to 15.20 meq O<sub>2</sub>/kg was recorded for this parameter. The highest values of acid and peroxide value were observed in butter extracted from the kernels stored in basket. The iodine index, the saponification and unsaponifiable content of the butter were affected in various extent. Overall, the kernels boiled prior to drying, stored in jute bag for a duration less than six months provided a butter with optimum quality characteristics.

**Key words:** *Pentadesma butyracea*, kernels, butter, packaging material, storage duration.

### INTRODUCTION

Traditional foods contribute to food security of millions of poorest people in Africa and to the preservation of the biological diversity of forest resources (Vantomme, 1999). *Pentadesma butyracea* Sabine (Clusiaceae) is a ligneous

forest species of multipurpose uses. It is widely distributed in Africa from Guinea-Bissau to the West of the Democratic Republic of Congo. The plant is known as "tallow tree" or "butter tree" in English, "arbre à suif" or

“arbre à beurre” in French, “Krinda” in Côte d'Ivoire, “Abotoasebie” in Ghana, “Agnuhé” in Gabon and “Kpangnan” or “Sesseido” in Benin. *P. butyracea* is found in the centre and northern part of Benin in forest galleries and along water ways (Avocèvou-Ayisso et al., 2011; Natta et al. 2010). The fresh kernels consumed like kola (Sinsin and Sinadouwirou 2003) are rich in edible butter similar to shea butter (Tchobo et al., 2007). The *P. butyracea* butter is generally extracted by traditional processing methods that involve roasting, churning and boiling of kernels. The resulted crude butter is sold in local markets and used for dietary and medicinal purposes. The fatty acid profile of *Pentadesma* butter is similar to that of the sheanut butter. However the content of unsaponifiable of the shea butter is higher than that of *P. butyracea* (Tchobo et al., 2013). The typical fatty acid composition of *P. butyracea* is (in mol-%) palmitic acid (C16) 3.6, stearic acid (C18) 47.00, oleic acid (C18:1) 52.00, linoleic acid (C18:2) 0.7, linolenic acid (C18:3) 0.2, arachidic acid (C20) 0.1 and others (Tchobo et al., 2009). The presence of five triacylglycerols (POO, POS, OOO, SOO, SOS), was observed in *P. butyracea* butter. SOO and SOS were the predominant triacylglycerols. The absence of tristearin (SSS) and a low content of triolein (OOO) were observed despite the high content of stearic and oleic acids. The triacylglycerol SOS was the main triacylglycerol with a concentration of over 50% whereas the SOO content varied between 35 and 45% (Tchobo et al., 2009). The social and economic values of *P. butyracea* were the subject of a study by Avocèvou-Ayisso and Sinsin (2009). The authors indicated that the various organs of the plant (kernels, leaves, flowers, bark, and roots) are used in food, cosmetic and for therapeutic purposes. Part of the derived butter, is exported towards the neighbouring countries (Togo) and the other sold at the regional markets or used to satisfy the domestic needs (Sinsin and Sinadouwirou, 2003).

In Benin, the harvesting period of the fruits of *P. butyracea* coincides with the raining season ((Sinsin and Sinadouwirou, 2003). After fruits collection, the women processors extract the kernel which can be stored for duration up to two years before processing. Our recent investigations revealed that the kernels undergo various pre-treatments such as boiling, sun drying and roasting before storage (Ayegnon et al., 2015). The pre-treated kernels are stocked in jute bags, in bowls, in the baskets and sometimes on the flour. During the storage, the kernels can undergo various deteriorations, which are susceptible to alter the quality of the seed while inducing biochemical modifications in the derived butter. Very few works investigated the effects of the storage process on the quality of *P. butyracea* kernels and derived butter. The objective of this work was to evaluate the effect of

storage conditions on the kernels characteristics and on the quality of a derived butter. More specifically, the study evaluated the effects of three storage variables that is storage duration, the pre-treatments and the packaging materials on the acid and peroxide values, the saponification value, the unsaponifiable fraction of the butter, the iodine index and the colour characteristics of the *Pentadesma* butter.

## MATERIALS AND METHODS

### Plant material

Fresh fruits of *P. butyracea* were collected from May to June 2013 in the forest galleries of Péperkou village in the community of Toucountouna (10°20' - 10°45' N and 1°10' - 1°40' E) located in the Northwest of Benin. Eighty kilograms of *P. butyracea* fruits were randomly collected from different trees of *P. butyracea*. The fruits were stored in a dark cool box at 4°C and transported to the laboratory for analysis. In the laboratory, the fruits were de-pulped and kernels were cleaned to obtain fresh kernels which undergone various treatments prior to storage (Figure 1).

### Experimental design

An experimental design with three factors that is storage duration, the pre-treatments and the packaging materials was used to study the effects of storage conditions on the *P. butyracea* kernels and the derived butter quality. The storage duration varied from 0 to 12 months and the kernel pre-treatments includes the boiling and the drying. The packaging materials included the jute bag and the basket container. The boiling was performed at a temperature of 90-100°C during 60 min and kernel drying was done at a temperature of 45°C during 72 h. Samples were stored at ambient temperature (temperature: 29.5°C; relative humidity 65±3%). The responses were moisture content, the acid and peroxide values, the saponification value, the unsaponifiable fraction of the butter, the iodine index and the colour characteristics of the butter.

### Characterisation of the kernels during storage

Samples of *P. butyracea* kernels were withdrawn at different storage duration and analyzed for their moisture content (AOAC, 2002). The rate of the kernels deterioration during storage was determined by counting the number of kernels deteriorated among a subsample of hundred kernels taken randomly. The counting was repeated three times and the average values were reported.

### Oil extraction

Butter was extracted using the traditional procedure (Ayegnon et al., 2015). The kernels are sorted and crushed. Approximately 300 g of crushed kernels were roasted at 120°C during 30 min. The roasted kernels were ground into fine paste. Some tepid water was added and the mixture was churned for 2 h using a mixer (Kenwood KM 280 series, 900W, china). The generated cream is washed with

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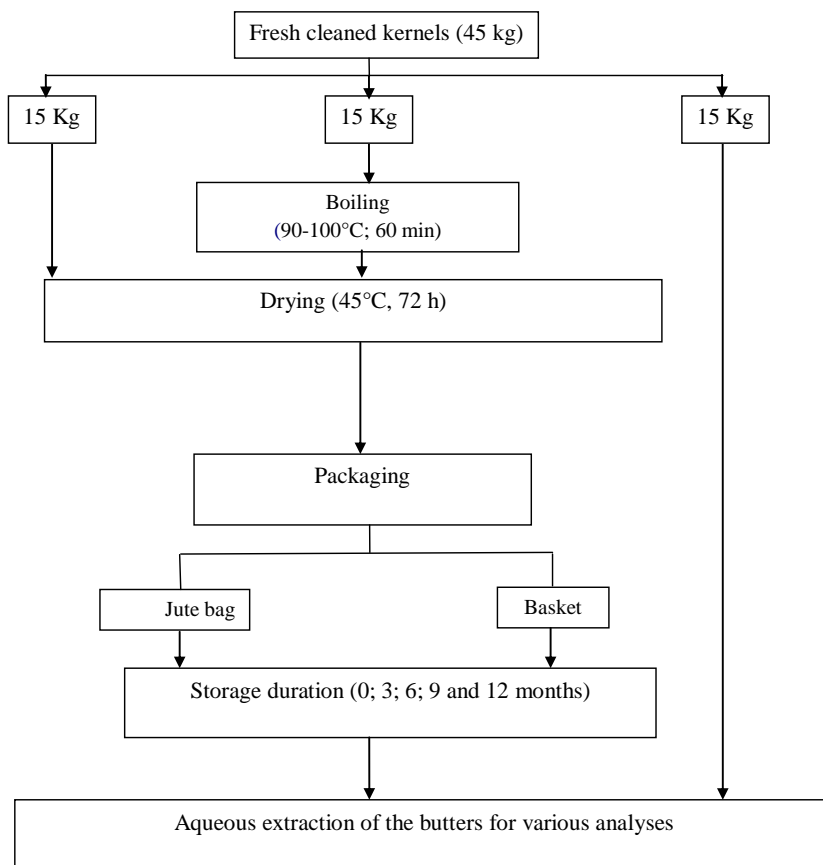


Figure 1. Experimental design.

water, to yield the raw butter which was heated at a temperature of 120-130°C. The derived oil was filtered and cooled to generate butter. The butter was preserved at 4-7°C in the refrigerator until various laboratory analyses.

#### Physicochemical analyses of the butter

Colour measurements were performed using the chromameter Konica Minolta (CR410). Results were expressed as  $L^*$  (brightness) and  $b^*$  (yellowness). The colour coordinates of the white ceramic standard are:  $Y = 86.10$ ,  $X = 0.3194$ ,  $y = 0.3369$ . Various chemical analyses were performed as well. Thus, the saponification value was determined according to the standards methods ISO 3657 (2006). The unsaponifiable fraction was determined after treatment with a solution of ethanolic potassium hydroxide and extraction by diethyl ether (NB ISO 3596, 2006); the acid and peroxide values and the iodine index were assessed by titration using NB ISO 3960, 2006; NB ISO 3961, 2006; NB ISO 660, 2006 methods respectively.

#### Statistical analysis

Statistical analysis were performed using the statistical program SPSS16.00 (SPSS, Chicago, IL, USA) and the one-way ANOVA model was used applying the Tukey's post-hoc test to evaluate significant difference among means at  $p < 0.05$ .

## RESULTS AND DISCUSSION

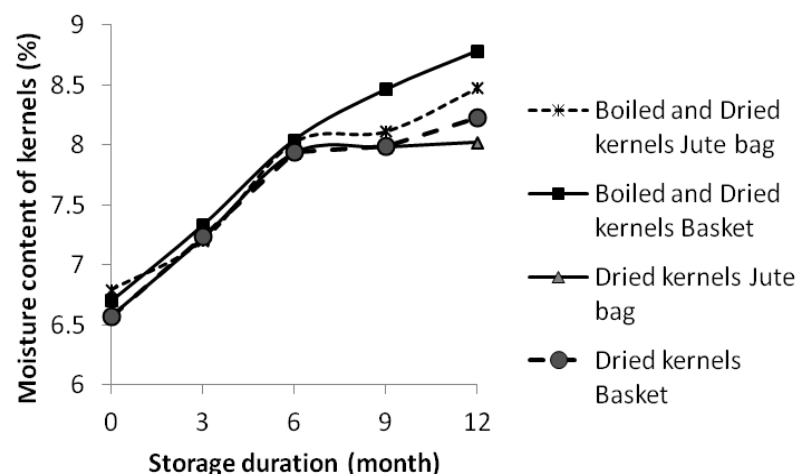
### Effects of the storage conditions on the kernels quality

The effects of factors that is kernels pre-treatments, packaging material and the storage duration on the kernels moisture content and the quality parameters of the derived butter are presented in Table 1. The storage duration and the pre-treatments applied (directly dried kernel, boiled and dried kernel) significantly affected the kernel moisture content which increased from a mean value of 6.68% to 8.51% for all treatments after twelfth months of storage. No significant difference could be observed in the moisture content of the kernels stored in jute bag and those stored in basket along the storage duration (Figure 2). In a study by Aïssi et al. (2012), roasted kernels, and boiled and dried kernels of *P. butyracea* stored for 24 months reached similar levels of moisture content (7.85 and 8.24% respectively). Increased level of moisture content could lead to kernels deterioration as a result of increasing microbial and enzymatic actions. We inspected the kernels throughout

**Table 1.** Analyze of variance showing the effect of the storage duration, the pretreatment and packaging material on physic-chemical characteristics of the butter.

Factors	Fischer value (F)								
	DL	MC	Acid	Peroxide	Saponification	Unsaponifiable	Iodine	L*	b*
Storage duration	4	40.502***	494.124***	369.585***	187.131***	496.275***	19.667***	3.872***	151.495***
Packaging	1	53.314***	1.250	18.420***	20.169***	0.687	1.531	488.093***	38.898***
Pretreatment	2	1.326	0.006	164.528***	343.852***	832.011***	32.987***	1.358*	46.844***
Storage duration*Packaging	4	3.364*	7.861***	8.465***	1.262	0.285	0.114	2.528***	16.802***
Storage duration*Pretreatment	4	0.048	4.922***	28.301***	1.372	491.169***	1.316	701.036***	13.364***
Packaging*Pretreatment	1	0.021	3.200	8.298*	7.778*	0.157	1.156	2.262***	8.868***
Duration*Packaging*Pretratment	4	0.089	3.068*	8.330***	0.562	0.701	0.112	5.112***	9.679***

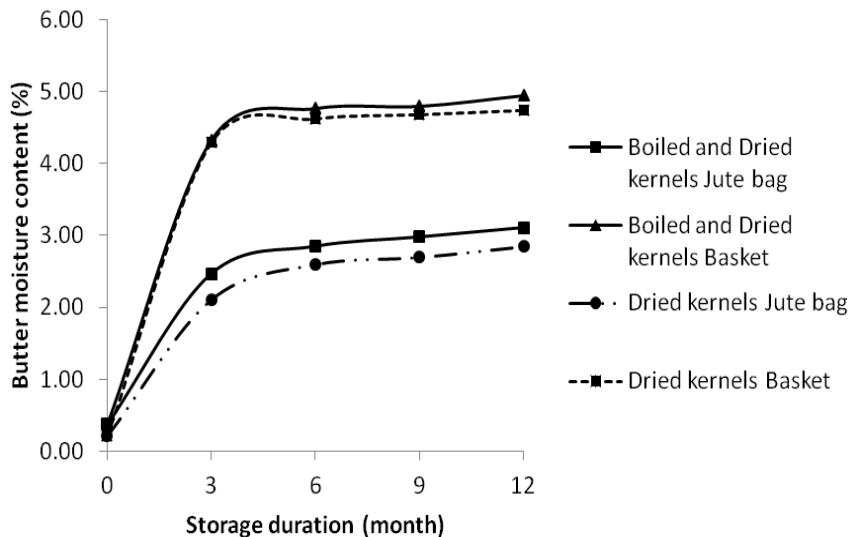
\*Significant with the threshold of 5%; \*\*\*Significant with the threshold of 1%.

**Figure 2.** Effect of storage duration, pre-treatments and packaging materials on moisture content of *P. butyracea* kernels.

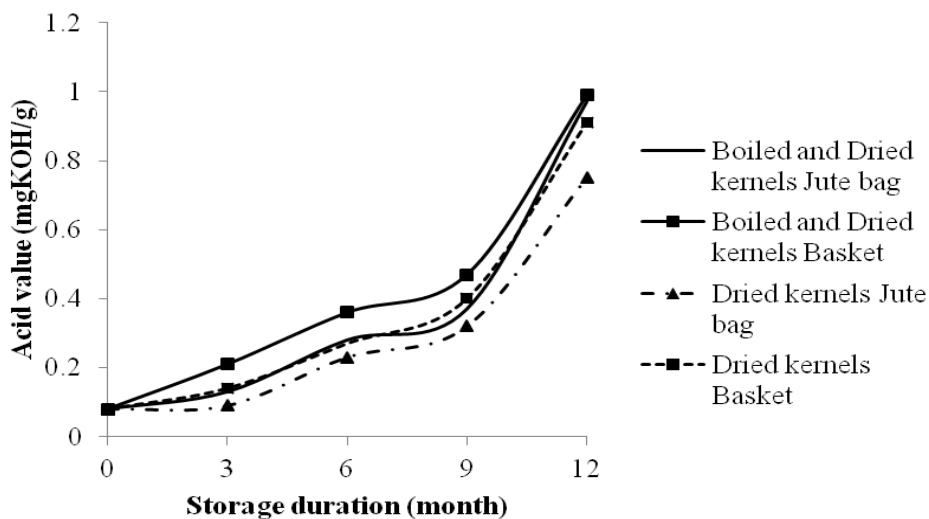
the storage duration and observed that samples stored for longer duration showed higher rate of kernels deterioration. There is a correlation between kernel moisture content and the propor-

tion of seed damaged ( $r = 0.63$ ,  $p \leq 0.001$ ). The highest rate of kernels degradation was recorded in samples boiled and stored in the basket whereas much as 31-33% of kernels were

damaged after 12 months of storage. Indeed, cumulative to increased level of moisture content, insect attacks favoured by kernel cracking during boiling and subsequent drying may accentuate



**Figure 3.** Effect of storage duration, pre-treatments and packaging materials on moisture content of *P. butyracea* butter.



**Figure 4.** Effect of storage duration, pre-treatments and packaging materials on acid value of *P. butyracea* butter.

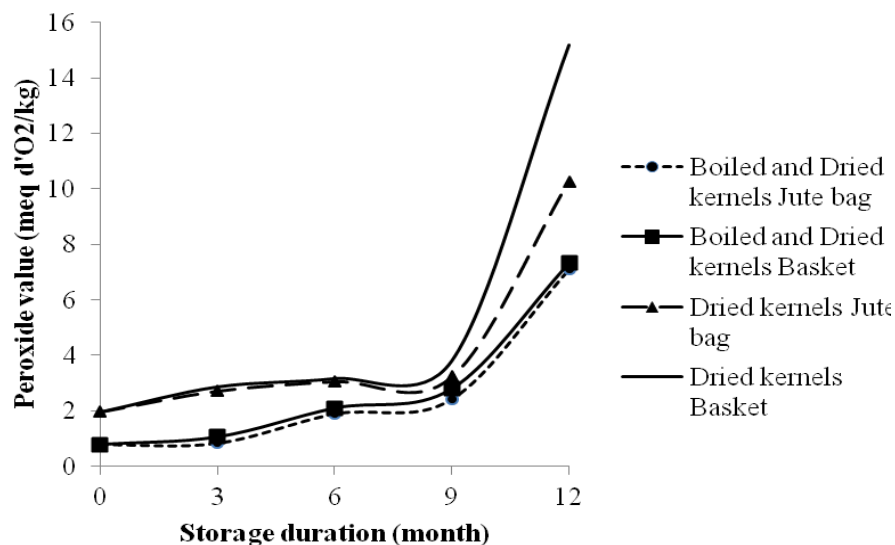
seed damage during storage.

#### Effects of the storage conditions on acid and peroxide values of derived butter

The butter moisture content was affected by the kernel storage duration and by the kernel pre-treatments. Longer kernel storage resulted in higher humidity in the derived butter. Such increase in the product water content may be detrimental to the butter quality since it may favour various biochemical deterioration processes.

Butters extracted from the kernels stored in the basket exhibited higher moisture content compared to those from kernels packed in jute bag due to high exposure of kernel to the relative humidity (Figure 3). The acid value of the butter was significantly affected by the storage duration ( $P \leq 0.001$ ) and the interaction between storage duration and packaging materials (storage duration\*packaging). Figure 4 shows the trend in the acid value of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. The butter acid value was similar for all treatments at the beginning of storage and averaged to



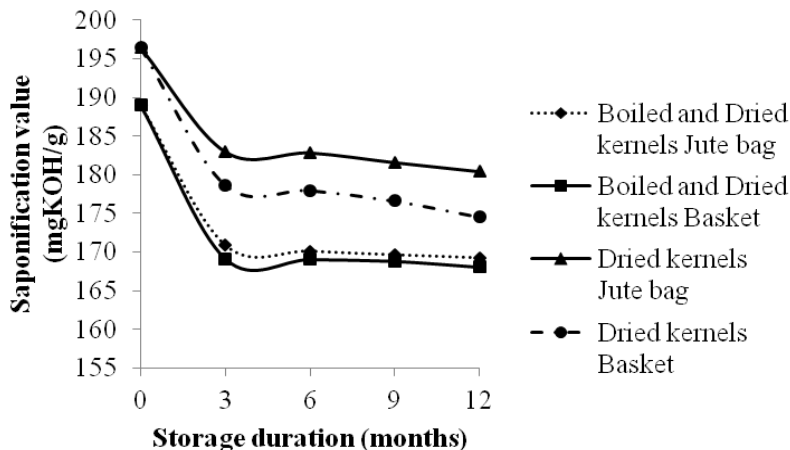


**Figure 5.** Effect of storage duration, pre-treatments and packaging materials peroxide value of *P. butyracea* butter.

0.08 mg KOH/g. This value increased ( $P \leq 0.001$ ) to an average value of 0.95 mg KOH/g of butter after twelfth months of storage. For all samples, the acid value increased slowly in the storage period between 0 and 9 months and increased sharply thereafter. Studies on shea butter also revealed an increase in the fatty acid value as a result of longer kernel storage (Nkouam et al., 2007). Indeed, high acid value in the butter samples suggests an increase in the free fatty acids which may result from lipid hydrolysis. High moisture content of butter is favourable to such phenomenon and we found a significant correlation between the butter moisture content and its acid value ( $r = 0.49$ ,  $p \leq 0.01$ ). Mendez and Falque (2007), reported an increase in acidity of oil stored in PET plastic. Kapseu et al. (2005) indicated that the acid value of shea butter increases with the storage duration and the treatment conditions of the shea fruits. The authors assigned this increase to physiological activities in the fruits. During storage, fatty acids are degraded to produce some energy and precursors for the synthesis of new molecules. Various studies on other oleaginous kernels such as the works of Kapchie (2005) on the aiélé fruits (*Canarium Schweinfurthii Engl.*) and researches by Anhwange et al., (2010) on *Citrus lanatus* revealed that longer kernel storage resulted in an increased in level of acid value in the oil.

All the factors studied significantly affected the peroxide value of the butter. The analysis of variance revealed significant ( $P \leq 0.001$ ) effects of the kernel pre-treatments, the packaging materials, the storage duration, and their interaction on the peroxide value (Table 1). Figure 5 shows the trend in the peroxide value of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. Overall, the

peroxide value of the butter increased with the storage duration for all treatments. During the storage, the modification pattern of the peroxide was comparable to that of the acid value. Notably, there was a slow increase between 0 and 9 months of storage followed by a sharp increase till the twelfth month of preservation. Butters extracted from kernels boiled before drying and showed lower peroxide value compared to those from kernel dried without boiling. During the heating process of kernels, denaturation of native lipases may occur, which would have limited the oxidation of fatty acids in the butters extracted from the boiled kernels. The mean peroxide value increased from 0.84 to 7.32 meqO<sub>2</sub> / kg in butter extracted from boiled and dried kernels while it varied from 2.72 to 15.20 meqO<sub>2</sub> / kg in butter from kernels dried without boiling after 12 months of storage. Values obtained in this study are similar to findings by Aïssi et al (2011) who reported a value of 0.83 meqO<sub>2</sub> / kg for butters extracted from boiled and dried kernels of *P. butyracea* and 1.00 meqO<sub>2</sub> / kg for the butters from roasted kernels. Mégnanou and Nianké (2013) found a modification in the peroxide value of stored shea butter in the range of 2.79 to 10.30 meq O<sub>2</sub>/kg within four weeks of storage. In this study, the peroxide value found in butter extracted from kernels dried without boiling after 12 months of storage which is higher than the tolerated value in the cosmetic and food sectors which are 10 meq O<sub>2</sub>/kg and 15 meq O<sub>2</sub>/kg respectively (Codex Alimentarius, 2006). Indeed, when the concentration of peroxide reaches a certain level, complex changes occur with the formation of ketones, aldehydes and hydroxyl groups which are volatile and mainly responsible for the off-flavours (rancidity) and odours (Abdulrahim et al., 2000).



**Figure 6.** Effect of storage duration, pre-treatments and packaging materials on saponification value of *P. butyracea* butter.

### Effects of the storage conditions on the saponification value and unsaponifiable fraction of the butter

The saponification value refers to the average length of the fatty acid chains which make up fat. It is an indicator of the soap making ability of oil. High saponification value indicates the presence of high percentage of fatty acids and triacylglycerol in the oil (Omolaro et al., 2011). The present study revealed significant ( $P \leq 0.001$ ) effects of the three studied factors on the saponification value of the butter extracted from the stored kernels (Table 1). Figure 6 shows the trend in the saponification value of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. There is a drastic decrease in the saponification components of the butter during the first three months of storage. No significant change occurred in this butter parameter afterward. The saponification value decreased from 188.98 to 168.05 mg KOH/g in butter extracted from boiled and dried kernels over 3 months of storage. It varied from 196.46 to 174.53 mg KOH/g in butter extracted from kernels dried without boiling during the same storage period. Clearly, butters from kernels boiled prior to drying showed low levels of saponification value compared to those from kernels dried without boiling whatever the storage duration. Our results are similar to findings by Aïssi et al. (2011). The saponification values found in our butters are in the range between 160 and 195 mg KOH/g of butter, which falls in the normal interval recommended by the Regional Technical Committee (RTC, 2006) for vegetable oils of good quality. Also, our data are similar to the saponification values reported for common oils such as soya bean (189 - 195 mg KOH/g), peanut (187 - 196 mg KOH/g) and cotton seed oil, (189 - 198 mg KOH/g) (Codex Alimentarius, 1993). Nevertheless, saponification values found for *P. butyracea* butter in this study are higher than that of shea butter (Warra et al.,

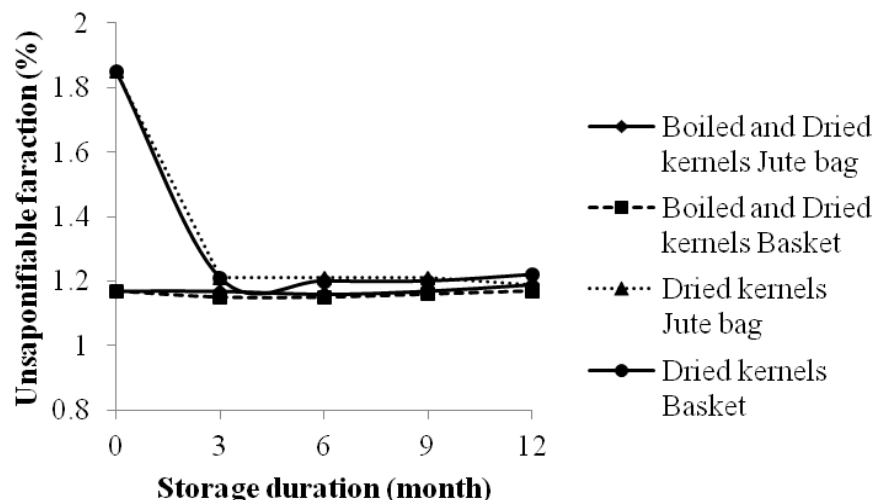
2011) indicating that this kind of butter has potential to be used in the cosmetic industry for soap making.

The analysis of variance revealed significant effects of the kernel pre-treatments, the storage duration and the interaction pre-treatments \* storage duration ( $P \leq 0.001$ ) on the unsaponifiable fraction of the derived butter (Table 1). The type of packaging materials used did not affect ( $P > 0.05$ ) the unsaponifiable fraction. Figure 7 shows the trend in the unsaponifiable fraction of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. Prior to storage, the kernels boiling resulted in a sharp decrease in the butter unsaponifiable fraction which remain unchanged during storage.

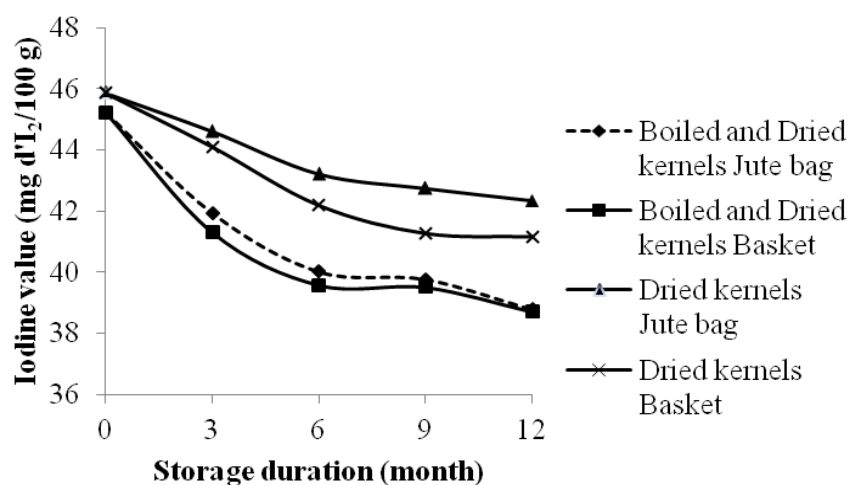
Reduction of thermo labile compounds such as tocopherols, carotenoids, triterpene alcohol, sterols, phenolics that account for unsaponifiable butter fractions may be reason for this reduction. Indeed, these substances contained in unsaponifiable fraction of the oil, have antioxidant and other health related benefits in animals and in human subjects and are useful in softening the skin (Goreja, 2004; Kochhar et al., 2000). During the storage course, the unsaponifiable fractions in the butter extracted from kernels dried without boiling and decreased within three months of storage (1.85 to 1.2%) and remain invariable afterwards. Clearly, thermal treatments are not favourable for unsaponifiable components concentration of the butter. Indeed, butters with a high unsaponifiable fraction are preferred for cosmetic and medicinal purposes due to the antioxidant and anti-inflammatory properties of the unsaponifiable fraction compounds such as tocopherols, phenols and sterols (Maranz and Wiesman, 2004; Honfo et al., 2013).

### Effects of the storage conditions on the iodine index of the butter

The iodine value expresses the degree of saturation of



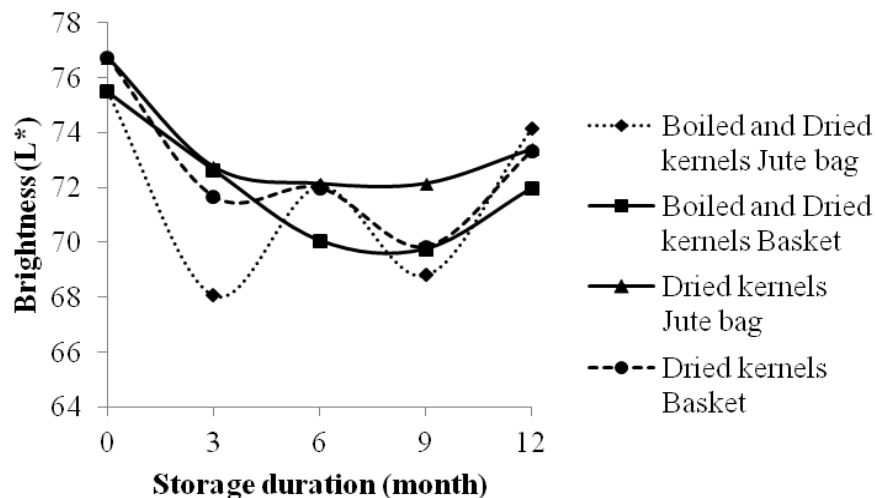
**Figure 7.** Effect of storage duration, pre-treatments and packaging materials on unsaponifiable fraction of *P. butyracea* butter.



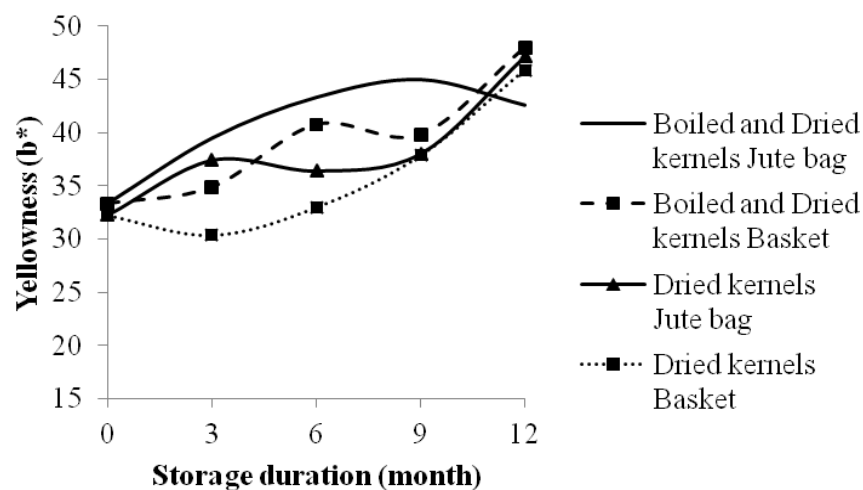
**Figure 8.** Effect of storage duration, pretreatment and packaging materials on iodine value of *P. butyracea* butter.

oil; it is an indicator of the storability of the oil. The higher the iodine numbers of an oil, the higher its degree of unsaponification, and the shorter its shelf-life is (Hui, 1996). The analysis of variance revealed significant ( $P \leq 0.001$ ) effects of the pre-treatments and the storage duration of the kernels on the iodine index of the butter (Table 1). Figure 8 shows the trend in the iodine index of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. From this figure, it is clear that butters extracted from kernels dried without boiling exhibited higher iodine values compared to butter from kernels boiled prior to drying whatever the storage duration. During the storage process, the iodine index decreased, varying from 45.23

to 39.58  $\text{mgI}_2 / 100 \text{ g}$  of butter after storage in the butters extracted from boiled and dried kernels. In the butters extracted from kernels directly dried this value decreased from 45.86 to 41.75  $\text{mgI}_2 / 100 \text{ g}$ . Values of the iodine obtained for butters of *P. butyracea* in this study are similar to data reported by Kouadio et al. (1990); Adomako et al. (1977) and Tchobo et al. (2013). The decreasing of the iodine index during the storage could be explained by a reduction in the number of double bonds by oxidation or hydrogenation phenomenon. Similarly, these biochemical reactions highly catalyzed by the high hydrothermal applications during boiling would be the main cause of discrepancy in iodine values of butters extracted from boiled and non-boiled kernels.



**Figure 9.** Effect of storage duration, pre-treatments and packaging materials on brightness ( $L^*$ ) of *P. butyracea* butter.



**Figure 10.** Effect of storage duration, pre-treatments and packaging materials on yellowness ( $b^*$ ) of *P. butyracea* butter.

Interestingly, iodine values obtained in this study are in agreement with the norm required for butter at the international level (58-72 mgI<sub>2</sub>/100 g of butter) (NBF 01-005, 2006). Likewise, the iodine values obtained for all samples in this study are consistently below 100 which allows classifying the *P. butyracea* butter in the category of non-drying oil which are useful in the production of soaps (Asuquo, 2008; Warra et al., 2013).

#### Effects of the storage conditions on the colour characteristics of the butter

There are significant ( $P \leq 0.001$ ) effects of kernels pre-

treatments, packaging materials and storage duration on the brightness ( $L^*$ ) and yellowness ( $b^*$ ) of butter (Table 1). In addition, the linear and the interactive effects of these factors were significant with respect to the two parameters mentioned. Figure 9 shows the trend in the brightness of the butter as function of the storage duration with respect to various pre-treatments and packaging materials. The brightness of the different types of butters tend to decrease during the storage. In opposite, the yellowness index increases (Figure 10). Kernels stored in jute bags exhibited relatively higher values for the yellowness index.

Similarly, butters extracted from the boiled and dried kernels showed a yellowness index relatively higher than

butter from directly dried kernels. The butter of *P. butyracea* is naturally yellow with bright colour and these colour characteristics are preferred by consumers (Ayegnon et al., 2015). Chukwu and Adgidzi (2008) found that the colour of shea butter varies, depending on the processing technique, in particular on the temperature applied during processing. Several studies have underlined the difference between the preparation modes of beige and yellow shea butters and the different sensorial characteristics associated (Mégnanou, 2008). Clearly, this study revealed that longer storage duration is favourable to the butter yellowness but detrimental to its brightness.

## Conclusion

The storage duration, the pre-treatments and the packaging materials of the kernels of *P. butyracea* affect the quality characteristics of the derived butter. Particularly, the colour, the peroxide and the acid values, the iodine index, the saponification and unsaponifiable fractions of the butter are affected in various extents. The packaging materials currently used in the different production sites of Benin to store the *P. butyracea* kernels affect the quality of the derived butter. More specifically, the basket is less effective, compared to the jute bag, in preserving the quality of the butter within 6 months of storage. Overall, this study shows that it is advantageous to treat the *P. butyracea* kernels by boiling before storage.

## Conflict of interests

The authors did not declare any conflict of interest.

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## REFERENCES

- Abdulrahim MO, Hassan A, Bahago EI (2000). Practical manual on food technology, nutritional dietetics for schools and industries. Paper presented in the Proceedings of the National Science and Technology Forum, College of Science and Technology, Kaduna Polytechnic, Kaduna, Nigeria.
- Adomako D (1977). Fatty acid composition and characteristics of *Pentadesma butyracea* fat extracted from Ghana seeds. *J. Sci. Food Agric.* 28:384-386.
- Aïssi MV, Djoumonlo AM, Sossa HA, Soumanou MM (2012). Evaluation of the physicochemical quality of butter from *Pentadesma butyracea* sabine stored seeds. *Anal. Sci. Agro.* 16(2):10-19.
- Aïssi MV, Tchobo FP, Natta AK, Piombo G, Villeneuve P, Sohounhloué DCK, Soumanou MM (2011). Effet des prétraitements post-récolte des amandes de *Pentadesma butyracea* (Sabine) sur la technologie d'extraction en milieu réel et le qualité du beurre. *OCL* 18 (6) : 384-392.
- Anhwange BA, Ikyenge BA, Nyiataghe DT, Ageh JT (2010). Chemical Analysis of *Citrullus Lanatus* (Thunb.), *Cucumeropsis Mannii* (Naud.) and *Telfairia Occidentalis* (Hook F.) Seeds Oils. *J. Appl. Sci. Res.* 6(3):265-268.
- AOAC (2002). Official methods of analysis, 16 th edn. Washington, DC: Association of Official Analytical Chemists.
- Asuquo JE (2008). Studies on the adsorption of some selected metallic soaps onto hematite. Ph.D. Dissertation, University of Port Harcourt, Nigeria.
- Avocèvou-Ayisso C, Sinsin B, Adégbidi A, Dossou G, Van Damme P (2009). Sustainable use of non-timber forest products: Impact of fruit harvesting on *Pentadesma butyracea* regeneration and financial analysis of its products trade in Benin. *For. Ecol. Manag.* 257 (8): 1930-1938.
- Avocèvou-Ayisso CMA (2011). Etude de la viabilité des populations de *Pentadesma butyracea* Sabine et de leur socioéconomie au Bénin. Thèse de doctorat. Université d'Abomey Calavi, Bénin. 223 p.
- Ayegnon BP, Kayodé APP, Tchobo FP, Azokpota P, Soumanou MM, Hounhouigan DJ (2015). Profiling the quality characteristics of the butter of *Pentadesma butyracea* with reference to shea butter. *J. Sci. Food Agric.* 10.1002/jsfa.7052. 7pp.
- Chukwu O, Adgidzi PP (2008). Evaluation of some physico-chemical properties of Shea-butter (*Butyrospermum paradoxum*) related to its value for food and industrial utilisation. *Int. J. Postharvest Technol. Innov.* 1 : 320-326.
- Codex Alimentarius Commission (1993). Graisses et huiles vegetales, Division 11, version abregee FAO/WHO Codex Stan 20 -1981,23 - 1981. Davine J, Williams PN.1961. The chemistry and technology of edible oils and fats.
- Codex Alimentarius Commission (2006). Programme mixte FAO/OMS sur les normes alimentaires. FAO, Rome.
- Goreja WG (2004). Shea Butter, The nourishing properties of Africa's best-kept natural beauty secrets. TNC International Inc.
- Honfo FG, Linnemann AR, Akissoe N, Soumanou M, Van Boekel MAJS (2013). Characteristics of traditionally processed shea kernels and butter. *Int. J. Food Sci. Technol.* 48:1714-1721.
- Hui L (1996). Edible oil and fat products: oils and oilseeds, bailey's industrial oil and fat products, 5<sup>th</sup> Edn. Wiley, New York. pp.109-110.
- Kapchie NV (2005). Les fruits de l'aiélé (*Canarium schweinfurthii* Engl.): Recherche des causes de durcissement et conservation humide, Thèse de Doctorat/PhD, ENSAI-Université de Ngaoundéré, Cameroun, 217p.
- Kapseu C, Womeni HM, Ndjouenkeu R, Tchouanguép MF, Parmentier M (2005). Influence des methods de traitement des amandes sur la qualité du beurre de karité. *Procédé et Biologie des Aliments.* 3: 1-18.
- Kochhar SP, Gertz C, Klostermann S (2000). A new method to determine oxidative stability of vegetable fats and oils at simulated frying temperature. In: *Lipids, Fats and Oils. Opportunities and Responsibilities in the New Century.* Joint International Congress and Expo. Würzburg, Germany, October 8-10.
- Kouadio K, Kossa A, Kamenan A (1990). Potentialités nutritionnelles de la graine de *Pentadesma butyracea* Sabine. *Agron. Afr.* 2: 126-129.
- Maranz S, Wiesman Z, Bisgaard J, Bianchi G (2004). Germplasm resources of *Vitellaria paradoxa* based on variations in fat composition across the species distribution range. *Agrofor. Syst.* 60:71-76.
- Mégnanou RM (2008). Contribution à l'étude du beurre de karité produit en Côte d'Ivoire et optimisation qualitative de sa fabrication artisanale. Thèse Unique de Doctorat. Université de Cocody, Abidjan (Côte d'Ivoire), p. 135.
- Mégnanou RM, Niamké S (2013). Contribution to the constitution of shea butter sensorial standard based on Ivoirian consumers criteria. *Int. J. Res. Biosci.* 2(1):13-21.
- Mendez AI, Falque E (2007). Effect of storage time and container type on the quality of extra-virgin olive oil. *Food Control* 18 : 521-529.
- Natta A, Sogbégnon R, Tchobo F (2010). Connaissances endogènes et importance de *Pentadesma butyracea* (Clusiaceae) pour les populations autochtones au Nord Ouest Bénin. *Fruit Veg. Cereal Sci. Biotechnol.* 4:18-25.
- NB ISO 3657 (2006) Normes Béninoises pour les corps gras d'origine



- animale et végétale: détermination de l'indice de saponification. CEBENOR (Centre Béninois de Normalisation). 9p.
- NB ISO 3960 (2006) Normes Béninoises pour les corps gras d'origine animale et végétale: détermination de l'indice de peroxyde. CEBENOR (Centre Béninois de Normalisation). 9p.
- NB ISO 3961 (2006) Normes Béninoises pour les corps gras d'origine animale et végétale: détermination de l'indice d'iode. CEBENOR (Centre Béninois de Normalisation). 8p.
- NB ISO 660 (2006) Normes Béninoises pour les corps gras d'origine animale et végétale: détermination de l'indice d'acide et de l'acidité. CEBENOR (Centre Béninois de Normalisation). 13p.
- NBF 01-005 (2006) Normes Burkinabées pour le beurre de karité non raffiné. ABNOR (Agence Burkinabée de normalisation). 21p.
- Nkouam GB, Barth D, Dirand M, Tchatcheng JB (2007). Oil extraction from shea kernel (*Vitellaria paradoxa*, Gaertn.) and *Canarium* pulp (*Canarium schweinfurthii*, Engl) using supercritical CO<sub>2</sub> and hexane a comparative study. *Res. J. Appl. Sci.* 2: 646-652.
- Omolara OO, Dosumu OO (2011). Preliminary studies on the effect of processing methods on the quality of three commonly consumed marine fishes in Nigeria. In: Okoye COB, Ibeto CN, Ihedioha JN. Preliminary studies on the characterization of orange seed and pawpaw seed oils. *Am. J. Food Technol.* 6:422-426.
- RTC (2006). Regional Technical Committee comments on draft African regional standards for unrefined shea butter.
- Sinsin B, Sinadouwirou TA (2003). Valorisation socio-économique et pérennité du *Pentadesma butyracea* Sabine en galeries forestières au Bénin. *Cah. Agri.* 12:75-79.
- Tchobo F, Natta A, Barea B, Barouh N, Piombo G, Pina M, Villeneuve P, Soumanou M, Sohounhloue D (2007). Characterization of *P. Butyracea* sabine Butters of Different Production Regions in Benin. *J. Amer. Oil. Chem. Soc.* 84:755-760.
- Tchobo FP, Alitonou GA,, Noudogbessi JP, Laguerre M, Barea B, Georges P, Natta KA, Villeneuve P, Soumanou MM, Sohounhloue KCD (2013). Evaluation of the chemical composition of *Pentadesma butyracea* butter and defatted kernels. *Int. J. Biosci.* 3:101-108.
- Tchobo FP, Piombo G, Pina M, Soumanou MM, Villeneuve P, Sohounhloue DCK (2009). Enzymatic synthesis of cocoa butter equivalent through transesterification of *Pentadesma butyracea* butter. *J. Food Lipids* 16:605-617.
- Vantomme P (1999). FAO. Activités relatives aux produits forestiers non ligneux. OIBT, Actualités des Forêts Tropicales. 7:25-33.
- Warra A, Wawata I, Gunu S, Aujaka K (2011). Extraction and physicochemical Analysis of some northern Nigeria industrial oils. *Arch. Appl. Sci. Res.* 3:536-541.
- Warra AA, Jega1 SA, Ahmad AJ, Abbas HY (2013). Comparative Physico- chemical Analysis of Traditional and Hexane Extracts of Shea nut Fat. *App. Sci. Rep.* 3(1):100-102.

*Full Length Research Paper*

## Effects of various freezing and thawing techniques on pork quality in ready-to-eat meals

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**Meat rapidly decomposes and discolours due to oxidation and enzyme activity; therefore, it must be frozen when stored. This study investigates the effects of different freezing and thawing processes on pork quality. Pork meat was frozen by natural convection freezing (NCF, -38°C), individual quick-freezing (IQF, -45°C), or liquid nitrogen freezing (LNF, -100°C). Freezing was completed when the thermocouple temperature reached -12°C. The meat was then placed in a general showcase at -24°C for 24 h. Thawing was conducted by natural convection thawing (NCT, 25°C) or running water thawing (RWT, 10°C). The cooking loss and drip loss contents of the samples did not significantly differ, whereas the thawing loss contents were higher in the NCF sample than that in the other samples. Compared to fresh meat, the  $L^*$ ,  $a^*$ , and  $b^*$  colour values decreased and the total colour difference ( $\Delta E$ ) was similar in the samples subjected to IQF/RWT. The pH values of all the samples except for the one subjected to NCF were significantly increased than that in fresh meat ( $p < 0.05$ ). IQF/RWT Treatment resulted in the highest water-holding capacity and maintained homogenous tissue similar to fresh pork; however, the shear force value was lower than those in the other frozen/thawed samples. These results suggest that the IQF/RWT process was optimal for pork.**

**Key words:** Freezing, thawing, pork, shear force, pH.

### INTRODUCTION

Optimization of processed meat quality attributes, such as colour, pH, water-holding capacity (WHC), shear force, thawing, and cooking loss, are important to the meat processing industry (Mortensen et al., 2006). The meat quality attributes that are influenced by freezing processes depend on many factors, including the temperature, time, air speed, and rate of freezing and

thawing (Giddings and Hill, 1978; Nicholson, 1973). Freezing is the most effective process for the preservation of food quality. Freezing and thawing can greatly affect the structural and chemical properties of muscle foods, including muscle fibers, lipids, and proteins, all of which have the potential to significantly influence the quality properties of meat and vegetable

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products (Miller et al., 1980).

Freezing has many advantages for the preservation of meat, but it can result in the destruction of muscle fibers due to the formation of ice crystals of various sizes according to the freezing rate (Hong et al., 2005b). This may lead to problems during thawing, such as drip loss, various WHC contents, decreases in the gel-forming potentials of muscle fiber proteins, and reductions in the space within the myofibrils (Sakata et al., 1995; Huff-Lonergan and Lonergan, 2005). Classic freezing and thawing procedures change the texture and cooking properties of food, and this is probably due to the destruction of the membrane structure and concentration changes in the solute (Londahl, 1997). The development of new methods for the freezing and thawing of foods is required in food industries (Massaux et al., 1999).

Several novel freezing techniques, such as individual quick freezing (IQF) and liquid nitrogen freezing (LNF), have been developed in recent years. IQF is an improvement of classical air blast freezing, which generally entails temperatures of  $-18^{\circ}\text{C}$  or lower (Fennema et al., 1975). In IQF, small food pieces are frozen in an air blast freezer at temperatures that are lower ( $-30$  to  $-50^{\circ}\text{C}$ ) than that used for traditional freezing. IQF can freeze individual or bulk samples of various food groups, such as meat, vegetables, and fruits, in less time (Jo et al., 2014). Cryogenic freezing with liquid nitrogen results in high freezing rates, even at the center of the product, and faster freezing time compared with conventional air freezing (Zhou et al., 2010). However, the cost of the cryogenic liquid is high, and this system has the disadvantage of freeze cracking, which causes critical and irreversible damage (Lovatt et al., 2004).

While freezing is a simple and effective way for preserving food, the thawing of frozen food is also important in the process. During food thawing, thermal treatments can damage the chemical, physical, and microbiological properties of food (Hong et al., 2009; Boonsumrej et al., 2007). Minimum thawing times can reduce microbial decomposition, the deterioration of food product quality, and water loss from dripping or dehydration (Taher and Farid, 2001). Most meat thawing is performed within the temperature ranges of  $-5$  to  $-1^{\circ}\text{C}$ , and only a small fraction of thawing is performed within the temperature range of  $-24$  to  $-5^{\circ}\text{C}$  (Heldman, 1975). Thawing can play an important role in membrane decomposition as well as affect the sensory properties of the food (Nilsson and Ekstrand, 1995). The freeze-thaw process has negative effects on the physicochemical properties and overall quality of the food (Jeong et al., 2011). Therefore, guidelines for the conditions for the optimal processing for freezing and thawing need to be established.

The freeze-thaw process may affect the quality of meat differently depending on the species. Universally, frozen storage is necessary to increase shelf life because pork meat has one of the shortest shelf lives among meat products

due to fast microbial growth and lipid oxidation (Wulf et al., 1995).

The objective of this study was to investigate the changes in the physicochemical properties, microstructure, and quality of pork meat that result from different freezing [natural convection freezing (NCF), IQF, and LNF] and thawing [natural convection thawing (NCT) and running water thawing (RWT)] processes.

## MATERIALS AND METHODS

### Materials and sample preparation

Pork (crossbreed of Landrace  $\times$  Yorkshire  $\times$  Duroc, 6 month old hogs) samples (eye of round) were obtained from a commercial market (48 h postmortem; pH, 5.7–5.9). The fat and connective tissue were removed, and the pork was cut into a rectangular shape ( $1 \times 1 \times 5$  cm,  $90 \pm 0.5$  g) parallel to the muscle fiber direction. For the fresh (unfrozen) pork, parts of the samples were placed into a showcase at  $4^{\circ}\text{C}$  for 24 h. After freezing treatment, the sample was vacuum packaged in a polyethylene bag, individually. A thermocouple (k-type) was inserted into the center position of each sample in order to monitor the temperature of the samples during freezing and thawing.

### Freezing and thawing process

NCF was performed at  $-38^{\circ}\text{C}$  in a showcase, whereas IQF was conducted with the use of a  $-45^{\circ}\text{C}$  air blast freezer (SEO JIN Freezer Co., Ltd., Goyang-City, Korea). For LNF, the samples were sprayed in a cryo-chamber system ( $150 \times 30 \times 50$  cm [L  $\times$  W  $\times$  H], HyunDae FA, Korea) with four circular spray nozzles (MS TECH CO., LTD., Sungnam-City, Korea) with a spray angle of  $60^{\circ}$  and a flow rate of liquid nitrogen vapor of 9.0 L/min. The samples were cryogenically frozen ( $-100^{\circ}\text{C}$ ) for 2 min 30 s. The freezing was finished when the temperature of the thermocouple reached  $-12^{\circ}\text{C}$ . Each freezing treatment sample was divided into two groups and vacuum packaged in a polyethylene bag that was placed in a general showcase at  $-24^{\circ}\text{C}$  for 24 h. The thawing process was performed with two methods so that one group was thawed in running water (RWT) at  $10^{\circ}\text{C}$  and the natural convection thawing (NCT) treatment was kept at  $25^{\circ}\text{C}$ . Thawing was finished when the temperature center position reached  $4^{\circ}\text{C}$ . The temperature-time profiles of all of the samples were observed by connecting the thermocouple with a mobile corder (MV-100, Yokogawa Electric Corporation, Tokyo, Japan).

### pH measurements

The pH values of the prepared samples were measured with a pH meter [S-220, Mettler-Toledo (Schweiz) GmbH, Greifensee, Switzerland]. Five grams of each sample was mixed with 45 mL of distilled water and homogenized at 12,000 rpm for 1 min with a homogenizer (HP-91, SMT Co. Ltd., Japan).

### Thawing loss and cooking loss

After the thawing treatment, the pork surface exudate was removed with a towel, and the samples were weighed. The thawing loss was determined by calculating the difference in the pre-freezing and post-thawing weights. After determining the thawing loss, the samples were bagged in polyethylene pouches and thermally

treated in an 80°C water bath (DX9, Hanyoung Nux Co., Ltd., Namgu, Incheon, Korea) until the core temperature reached 75°C. Cooking loss was calculated as the difference in the weights from before cooking to after cooking.

$$\text{Thawing loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

$W_1$ : weight of the sample after freezing (g)

$W_2$ : weight of the sample after thawing (g)

$$\text{Cooking loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

$W_1$ : weight of the sample after freezing and thawing (g)

$W_2$ : weight of the sample after thermal treatment (g)

### Water-holding capacity (WHC)

WHC was measured with modification of the method of Hong et al. (2005a). One gram of each thawed pork sample was weighed and then placed into a centrifuge tube with absorbent cotton. The samples were centrifuged with a centrifuge separator (1736R, LABOGENE, Korea) at 1,500 × *g* for 10 min at 4°C. After centrifuging, the pork was removed from the tube, and the weights of the centrifuge tubes were determined before and after the drying. The WHC was expressed as the percentage of moisture content in the meat.

$$\text{WHC(\%)} = \left(1 - \frac{W_3 - W_2}{W_1}\right) \times 100$$

$W_1$ : weight of the sample after centrifuging (g)

$W_2$ : weight of the tube, including the cotton, after centrifuging (g)

$W_3$ : weight of the tube after the sample was removed and after centrifuging (g).

### Shear force measurement

The samples from each batch were cut into cuboids (1 × 1 × 5 cm). The shear force of the pork samples was determined before and after cooking in quintuplicates with a texture analyzer (CT3, Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA) that was equipped with a v-type plain probe. The texture analysis conditions were as follows: compression type, 10 kg force load cell; test speed, 2.5 mm/s; target distance, 15 mm; and trigger loads of 900 g and 650 g on uncooked and cooked samples, respectively. The test was repeated at least 16 times. The maximum peak force (kg) was used as the indicator of the texture parameter.

### Colour measurement

The colour change of each sample was determined with a colourimeter (CR-400, Konica Minolta Inc., Tokyo, Japan) that was calibrated with a white standard plate ( $L^* = +97.83$ ,  $a^* = -0.43$ ,  $b^* = +1.98$ ). The CIE  $L^*$ ,  $a^*$ , and  $b^*$  values were determined as indicators of brightness ( $L$ ), red to green colour ( $a$ ), and yellow to blue colour ( $b$ ). To measure the colour changes, four pieces of pork were arranged in the direction of their longest length. The total colour difference ( $\Delta E$ ) was numerically calculated by determining the colour difference between the fresh meat and the treated samples with the following equation:

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

### Light microscopy

Light microscopy of fresh and frozen pork tissue was conducted on 0.2 cm-thick sections of formalin-fixed, paraffin-embedded samples stained with hematoxylin and eosin (H and E; BBC Biochemical, USA), using autostainer (Leica autostainer XI ST5010 Autostainer XL, Leica Microsystems Ltd., Korea).

### Statistical analysis

All of the reported values are the average of three (or more) experiments. Analysis of variance and Duncan's tests were conducted at the 95% confidence level ( $p \leq 0.05$ ) with SPSS 20.0 software (IBM Corporation, Armonk, NY, USA) in order to determine the significance of the differences in the results.

## RESULTS AND DISCUSSION

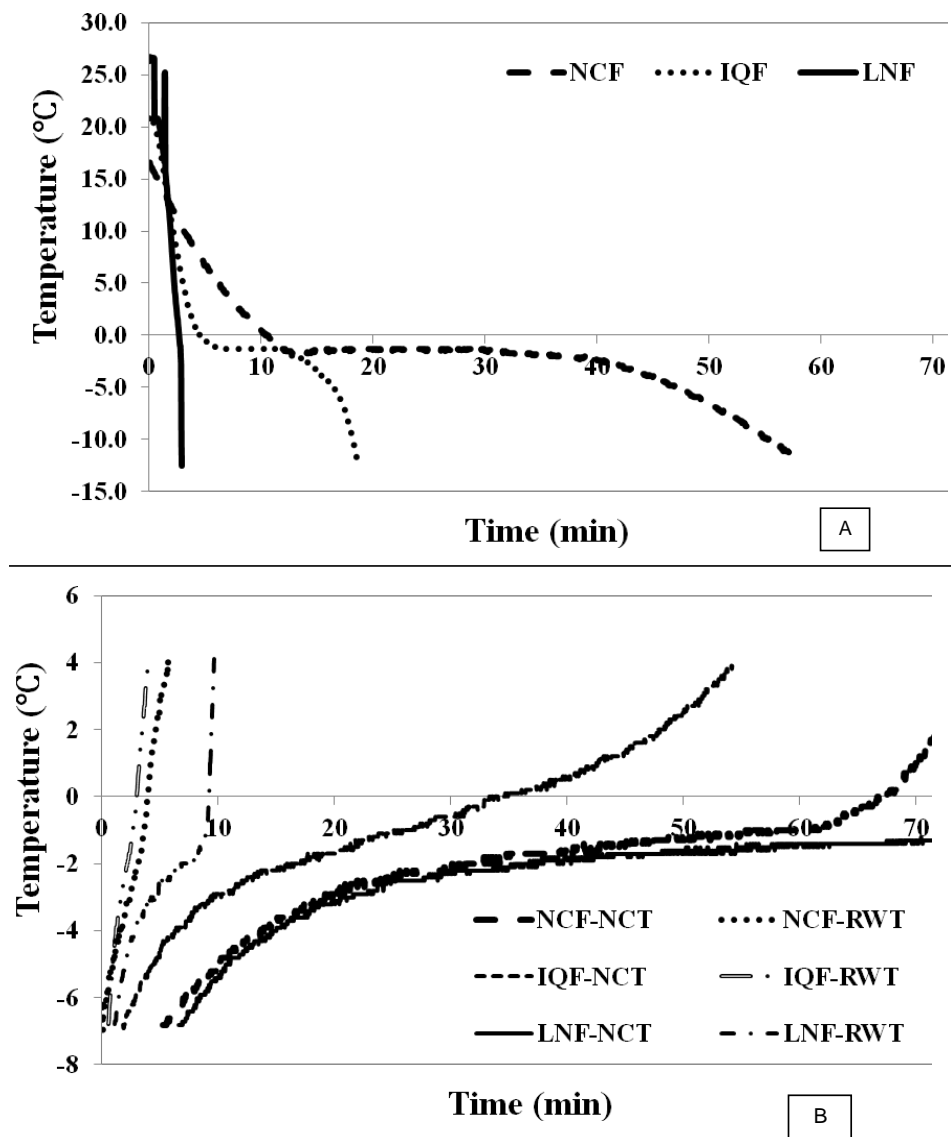
### Temperature-time profile

Figure 1 shows the time-temperature profiles of the pork treatment during freezing and thawing. The freezing time for the core temperature of the pork to reach -12°C was 58 min in the NCF treatment. IQF treatment showed rapid freezing compared to NCF, and the freezing time was estimated as 18 min. The LNF-treated pork showed the most rapid temperature drop among the freezing treatments, and the center temperature reached -12°C in 3 min. These results were in accordance with the freezing temperature of each treatment. Based on Boonsumrej et al. (2007), cryogenic freezing was favorable as a rapid freezing technique compared to air-blast freezing or commercial freezing, and this was in agreement with the results of our study.

For the thawing method, the overall thawing times of RWT and NCT were well differentiated (Figure 1b). All of the RWT treatments thawed within 10 min compared to the NCT treatments that took longer than 30 min. Although the NCT treatment was conducted at a higher temperature (25°C) than the RWT treatment (10°C), the results indicated that RWT was more advantageous than NCT for the rapid thawing. In addition, the thawing times of the samples differed according to the type of freezing that was applied. In the RWT treatments, the rapidity of the thawing occurred in the order of IQF, NCF, and LNF, and the same order was observed for the NCT treatments. Although the reason why the thawing rate was affected by freezing type was unclear in the present study, this study demonstrated that IQF that was followed by RWT was the best condition for the meat freezing and thawing processes.

### pH

The freezing and thawing treatments affected the pH of



**Figure 1.** Time-temperature profiles of the (A) freezing and (B) thawing processes. The freezing and thawing treatment included natural convection freezing (NCF), individual quick-freezing (IQF), liquid nitrogen freezing (LNF), natural convection thawing (NCT), and running water thawing (RWT).

the pork, as depicted in Figure 2. Irrespective of the thawing methods, NCF treatment resulted in pH values of 5.46 - 5.47, which was not significantly different from the 5.46 pH of the fresh control. However, pork that was frozen by IQF and LNF showed a significantly higher pH than that of the control ( $p < 0.05$ ), and a particular increase in pH was noticeable with LNF. For the thawing methods, the NCT treatments resulted in higher pH values compared to the RWT treatments ( $p < 0.05$ ). Consequently, the highest pH (5.58) was obtained with LNF treatment that was combined with NCT ( $p < 0.05$ ).

Various studies have reported inconsistent relationships of muscle pH and freezing/thawing treatment.

Leygonie et al. (2012) and Devine et al. (1995) have reported that frozen/thawed meat had a slightly lower pH than that of the fresh state due to the electrolyte exudate from the muscle tissue. Muela et al. (2010) postulated that the pH of fresh meat and frozen/thawed meat did not differ significantly.

Alternatively, Kim and Lee (2011) reported that frozen/thawed meat had a higher pH than fresh control meat because of partial denaturation of the muscle proteins. Those authors also insisted that the pH of treated meat is an important indicator of the physical properties of the muscle proteins. In the present study, it was clear that the impact of the treatment conditions on



**Table 1.** Effects of the freezing and thawing treatments on the water binding properties.

Freezing treatment <sup>1</sup>	Thawing methods <sup>2</sup>	Thawing loss	Cooking loss	Water holding capacity
Control			15.74±0.617 <sup>b</sup>	85.33±3.32 <sup>a</sup>
NCF		6.75±0.322 <sup>a,3</sup>	19.07±1.556 <sup>a</sup>	80.5±1.87 <sup>bc</sup>
IQF	NCT	4.48±1.23 <sup>b</sup>	18.9±0.795 <sup>a</sup>	79.18±2.14 <sup>bc</sup>
LNF		4.16±1.268 <sup>b</sup>	20.39±0.72 <sup>a</sup>	82.43±0.51 <sup>ab</sup>
NCF		4.67±1.282 <sup>b</sup>	21.69±1.842 <sup>a</sup>	77.68±1.87 <sup>3c</sup>
IQF	RWT	4.8±1.425 <sup>ab</sup>	19.97±2.613 <sup>a</sup>	85.19±1.230 <sup>a</sup>
LNF		3.75±1.21 <sup>b</sup>	20.18±1.448 <sup>a</sup>	79.65±1.575 <sup>bc</sup>

<sup>1</sup>Freezing treatment: NCF (natural convection freezing), IQF (individual quick freezing), and LNF (liquid nitrogen freezing). <sup>2</sup>Thawing treatment: NCT (natural convection thawing) and RWT (running water thawing). <sup>3</sup>Each value is expressed as the mean ± standard deviation of multiple measurements (n = 5). <sup>a-c</sup>Means within the same column with different superscript letters differ significantly (p < 0.05).

the physical state of the meat proteins was remarkable. Despite the finding that the LNF treatment was for a short period (2.5 min), an extreme temperature condition would result in cold denaturation of the muscle proteins, which would thereby increase the pH of the meat. Furthermore, thawing at relatively high temperature (25°C of NCT) was not favorable to minimize the quality loss of frozen muscle comparing to that thawed at low temperature (10°C of RWT). For the protein state, the application of LNF required the optimization of the proper operating conditions, such as the processing temperature and time.

### Water-binding properties

The water-binding properties of the frozen/thawed pork are given in Table 1. With the exception of NCF that was followed by NCT treatment, the overall thawing loss of the pork ranged from 3.75 to 4.80%, which was not significantly different among the treatments. However, the NCF/NCT treatment had the highest thawing loss (6.75%) among the treatments (p < 0.05). The highest thawing loss resulting from the NCF/NCT treatment was possibly related to the slow freezing and thawing rates. The NCF treatment involved a slow freezing rate by which the pork tissue would be more damaged than with the other freezing methods. Considering the decreased thawing loss of LNF that was followed by NCT treatment, the freezing rate appeared to influence the thawing loss of the pork rather than the thawing rate. However, it was obscure why LCF showed a small amount of thaw drip with RWT treatment. One possible explanation is that the frozen rapidly mean was not affected by the thawing methods, while rapid thawing was necessary when the meat was frozen slowly.

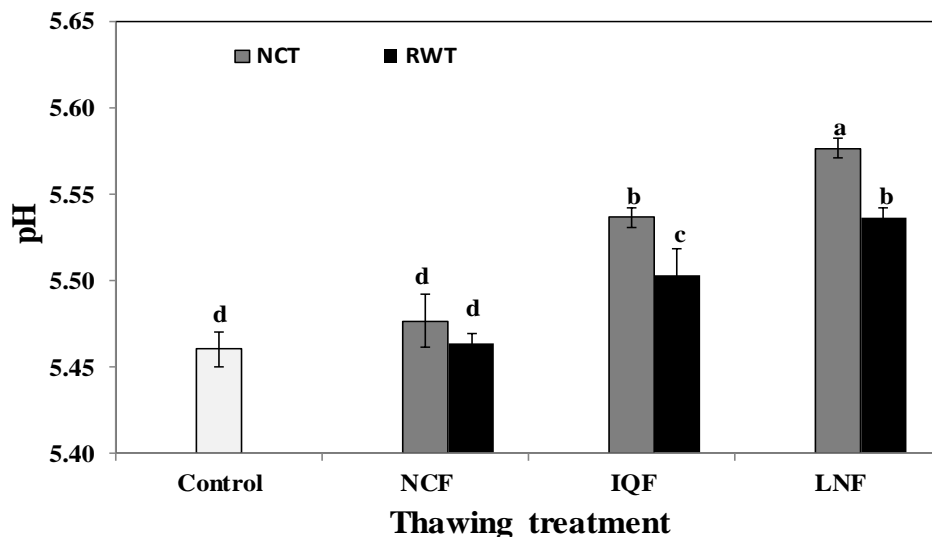
The cooking loss of the fresh control was 15.7%, and the loss was significantly lower than the losses from the freezing/thawing treatments (p < 0.05). Among the treatments, no significant differences in cooking loss were found, and the loss ranged from 18.9% to 21.7%. There was no doubt that the tissue damage that was caused by

ice crystallization and recrystallization attributed to the high cooking loss compared with fresh meat. For frozen/thawed meat, Mortensen et al. (2006) reported that a low freezing temperature and a high thawing temperature tended to result in high thawing loss and cooking loss. However, sample size is another important factor that affects the cooking loss of meat samples (Leygonie et al., 2011). In the present study, the meat was sampled in small strips that are used for home meal replacement products. The small size of the samples was compensated for by the insignificance of the cooking loss of the frozen/thawed treatments.

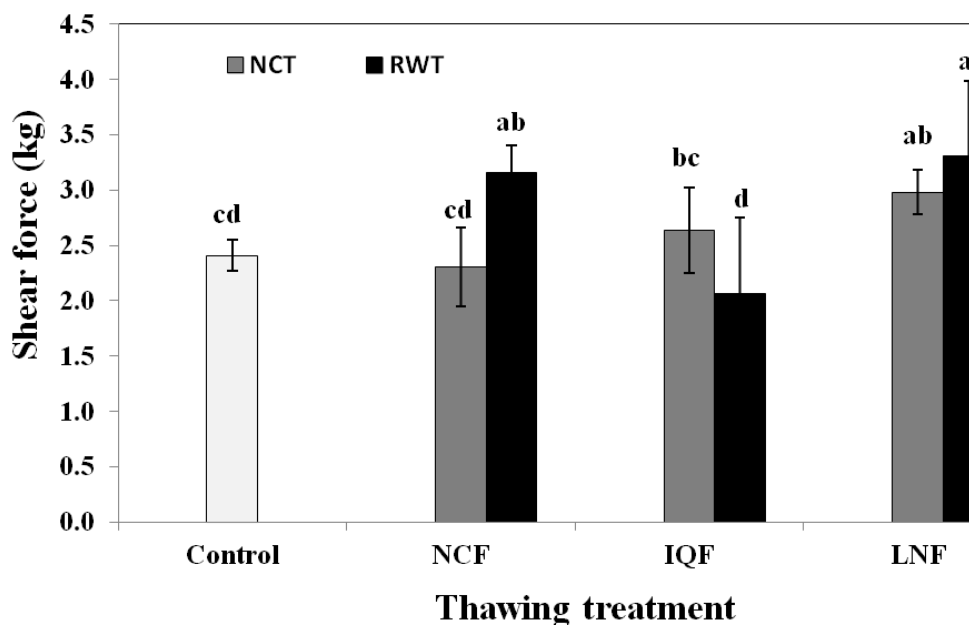
Compared to 85.3% of fresh control, the WHC of the treatments was slightly or significantly lower than the control and ranged from 77.7 to 85.2%. Jo et al. (2014) found that the WHC of muscle freezing/thawing treatment is lower than that of fresh controls, and this is in accordance the findings of this study. Miller et al. (1980) noted that the WHC percentage decreases for pork and beef meat because of damage to the muscle tissue from being frozen. Ngapo et al. (1999) showed that damaged cell membranes cause the drip exudate from the intracellular space to the extracellular space, which results in the easy release of drips from the muscle tissue. In this study, LNF that was followed by NCT (82.4%) and IQF that was followed by RWT treatment (85.2%) did not show significant differences in WHC compared with a control, while other treatments had lower WHCs than controls (p < 0.05). With respect to food hygiene, the thawing process is supposed to be conducted at a relatively low temperature in a short time, and, thus, RWT would be better than NCT in order to minimize the water binding properties of the treated meat. Therefore, these results suggest that IQF is the best application for meat freezing.

### Shear force

Figure 3 depicts the shear force of the cooked pork. The fresh pork had a shear force of 2.41 kg, and the frozen/



**Figure 2.** Effects of the freezing and thawing treatments on the pH of pork. The pH values of the control (fresh pork) and after the freezing and thawing treatments of natural convection freezing (NCF), individual quick-freezing (IQF), liquid nitrogen freezing (LNF), natural convection thawing (NCT), and running water thawing (RWT). Each value is expressed as the mean  $\pm$  standard deviation of multiple measurements ( $n = 5$ ). <sup>a-d</sup>Means with different superscript letters are significantly different ( $p < 0.05$ ).



**Figure 3.** Effects of the freezing and thawing treatments on the shear force of cooked pork. The control (fresh pork) and experimental samples were subjected to freezing and thawing with natural convection freezing (NCF), individual quick-freezing (IQF), liquid nitrogen freezing (LNF), natural convection thawing (NCT), and running water thawing (RWT). Each value is expressed as the mean  $\pm$  standard deviation of multiple measurements ( $n = 5$ ). <sup>a-d</sup>Means with different superscript letters differ significantly ( $p < 0.05$ ).

thawed treatment values ranged from 2.31 to 3.31 kg. Regardless of the thawing methods used, the shear force

of meat that was treated by IQF did not significantly differ than the control. However, the LNF and NCF treatments

**Table 2.** Effects of the freezing and thawing treatments on the CIE colour of pork.

Freezing treatment <sup>1</sup>	Thawing treatment <sup>2</sup>	L*	a*	b*	Total colour difference ( $\Delta E$ )
Control		59.16±1.7 <sup>a,3</sup>	8.02±0.94 <sup>a</sup>	7.1±0.76 <sup>b</sup>	
NCF	NCT	54.52±1.46 <sup>b</sup>	7.93±1.03 <sup>a</sup>	8.74±1.68 <sup>a</sup>	5.34±1.37 <sup>a</sup>
IQF		55.07±2.24 <sup>b</sup>	6.18±0.63 <sup>b</sup>	5.62±0.96 <sup>c</sup>	4.98±1.90 <sup>a</sup>
LNF		54.39±2.48 <sup>b</sup>	8.05±1.03 <sup>a</sup>	6.66±0.96 <sup>bc</sup>	5.03±2.36 <sup>a</sup>
NCF	RWT	54.84±2.29 <sup>b</sup>	7.74±1.06 <sup>a</sup>	6.75±1.22 <sup>bc</sup>	4.69±2.10 <sup>a</sup>
IQF		56.04±3.04 <sup>b</sup>	6.97±0.90 <sup>ab</sup>	7.14±0.75 <sup>b</sup>	4.19±1.75 <sup>a</sup>
LNF		53.76±1.24 <sup>b</sup>	7.37±1.28 <sup>a</sup>	5.52±0.55 <sup>c</sup>	5.81±1.27 <sup>a</sup>
NCF		54.84±2.29 <sup>b</sup>	7.74±1.06 <sup>a</sup>	6.75±1.22 <sup>bc</sup>	4.69±2.10 <sup>a</sup>

<sup>1</sup>Freezing treatment: NCF (natural convection freezing), IQF (individual quick freezing), and LNF (liquid nitrogen freezing). <sup>2</sup>Thawing treatment: NCT (natural convection thawing) and RWT (running water thawing). <sup>3</sup>Each value is expressed as mean ± standard deviation of multiple measurements (n = 5). <sup>a-c</sup>Means within the same column with different superscript letters differ significantly (p < 0.05).

that were followed by RWT treatment had significantly higher shear forces compared with controls (p < 0.05). Shanks et al. (2002) and Lagerstedt et al. (2008) reported that meat toughness was decreased by the freezing and thawing process. The decrease in the shear force might have been due to the loss in cell membrane durability that occurred as a result of ice crystal formation and the reduction in the shearing (Lui et al., 2010). The tenderization of meat can occur as a result of the activation of enzymes, such as those involved in proteolysis, and the loss of physical structure by ice crystal formation (Leygonie et al., 2012). In these investigations, however, the shear force was measured prior to the thermal processing. Alternatively, Lagerstedt et al. (2008) reported that the shear force of frozen meat is closely related to the storage period and storage condition. In addition, the frozen/cooked meat showed a higher shear force than the fresh/cooked meat did (Kolczak et al., 2005). In this study, IQF treatment resulted in the best tenderness of the meat, and the IQF was favorable for applying it as a quick freezing technique.

## Colour

The CIE colour parameters of the treatments were compared with those of fresh controls (Table 2). All of the freezing and thawing treatments had lower L\*, a\*, and b\* values compared with those of the control, with the exception of b\* in which the NCF/NCT samples showed a significantly lower b\* compared with the control (p < 0.05). Lind et al. (1971) obtained similar results in that the freezing rates did not have a significant effect on colour. The b\* value of the IQF/RWT sample had the most similar values as the fresh pork samples among the frozen/thawed samples. The total colour difference tended to be lower than those of the other samples, but the difference was not significant. The results can be explained by the IQF/RWT value being similar to those of fresh pork meat.

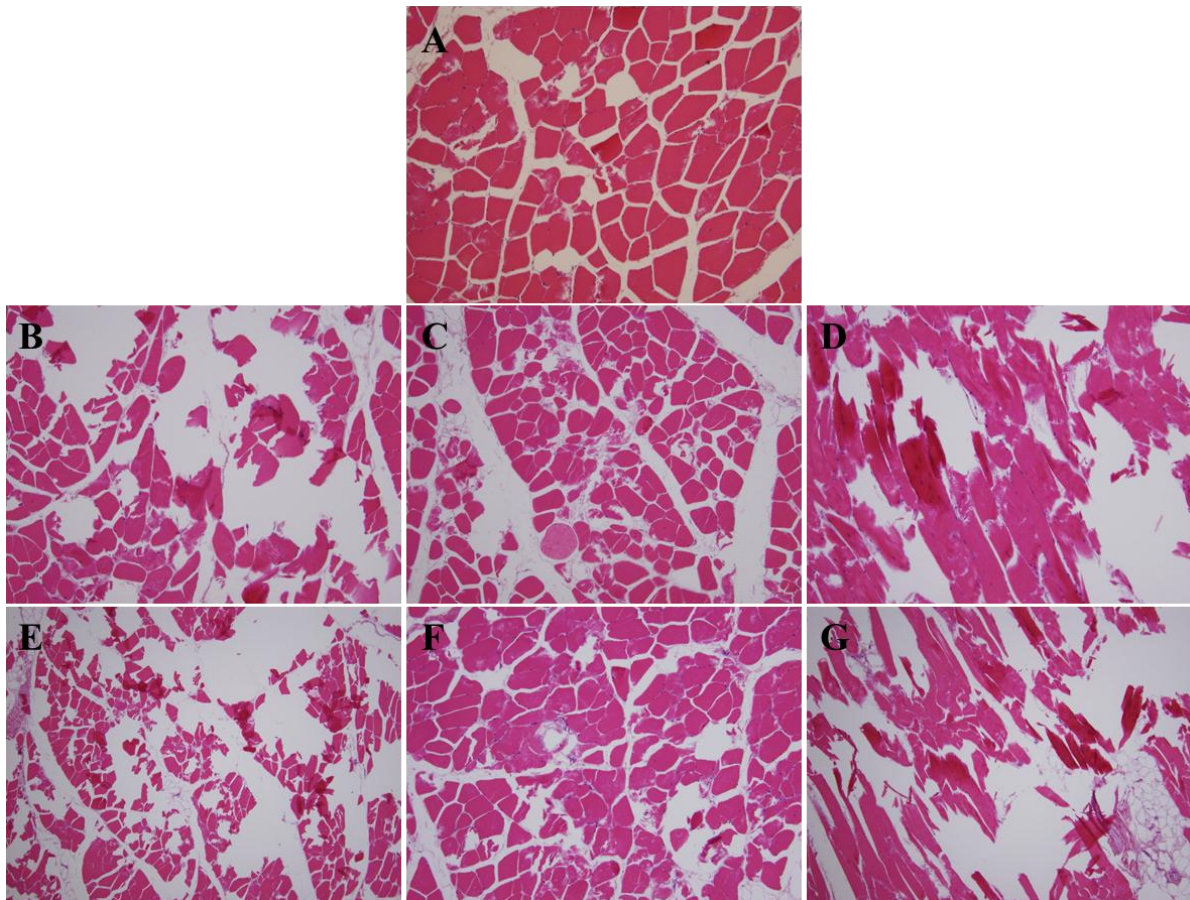
The hue angle of the meat product has been used to indicate the colour stability of fresh and processed meats (Brewer and Harbers, 1992). Leygonie et al. (2012) reported that the CIE L\*, a\*, and Chroma values in the visual test were significantly decreased in the frozen/thawed samples. These results suggest that the meat product should exhibit an overall browner and more somber appearance because of rapid oxidation of the myoglobin after freezing/thawing.

## Light microscopy

The light microscopy images of the pork samples are shown in Figure 4. For the raw pork (control), transverse sections of the myofibrils have most uniform shape and the myofibrils were maintained their integrity. However, segmental muscle and segmental coagulation necrosis in longitudinal section were observed after NCF and NCF treatments. This result could be explained by Jo et al. (2014) in which this phenomenon may result from ice crystal formation and recrystallization. Alternately, IQF maintained the condition of myofibrils, although their density was not as intense as that of the raw meat. Furthermore, the condition of myofibrils did not change after different thawing treatments. Based on Mortensen et al. (2006), cell structure of frozen muscle tissue was closely depending on freezing rate. Rapidly frozen muscle tissue showed broadly intact structure with partial damages, whereas the tissue frozen slowly showed completely damaged cell structure. Therefore, our results could demonstrate that tissue damage during freezing and thawing is inevitable, and confirm that tissue damage was more influenced by the freezing methods than thawing methods.

## Conclusion

This study compared the effects of different freezing and



**Figure 4.** Histological appearance of the frozen and thawed pork samples following the different freezing and thawing processes. (A) Control (raw pork), (B and E) natural convection freezing, (C and F) individual quick-freezing, (D and G) cryogenic freezing (B, C and D), natural convection thawing, and (E, F and G) running water thawing.

thawing treatments on the quality of pork. The factors of temperature, time, and the rates of freezing and thawing influenced the changes in the meat quality attributes, such as colour, thawing loss, WHC, and shear force. The results of this study suggested that IQF/RWT treatment is an effective process by which the meat quality is maintained.

#### Conflict of interests

The authors did not declare any conflict of interest.

#### ACKNOWLEDGMENT

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#### REFERENCES

- Boonsumrej S, Chaiwanichsiry S, Tantratian S, Suzuki T, Takai R (2007). Effects of freezing and thawing on the quality changes of tiger shrimp (*Penaeus monodon*) frozen by air-blast and cryogenic freezing. *J. Food Eng.* 80(1):292-299.
- Brewer MS, Harbers CAZ (1992). Effect of packaging on physical and sensory characteristics of ground pork in long-term frozen storage. *J. Food Sci.* 56(3):627-631.
- Fennema OR, Karel M, Lund DB (1975). Freezing preservation. In O. R. Fennema (Ed.), *Principles of food sciences part II. Physical principles of food preservation.* Marcel-Dekker, New York. pp. 173-215.
- Heldman DR (1975). *Food Process Engineering*, 2nd, AVI Publishing Co, Inc, Westport, CT.
- Hong GP, Park SH, Kim JY, Lee SK, Min SG (2005a). Effects of time-dependent high pressure treatment on physico-chemical properties of pork. *Food Sci. Biotechnol.* 14(6):808-812.
- Hong GP, Shim KB, Choi MJ, Min SG (2009). Effects of air blast thawing combined with infrared radiation on physical properties of pork. *Korean J. Food Sci. An.* 29(3):302-309.
- Huff-Lonergan E, Lonergan SM (2005). Mechanisms of water-holding capacity of meat: The role of post mortem biochemical and structural changes. *Meat Sci.* 71(1):194-204.
- Jeong JY, Kim GD, Yang HS, Joo ST (2011). Effect of freeze-thaw cycles on physicochemical properties and colour stability of beef semi membranous muscle. *Food Res. Int.* 44(10):3222-3228.
- Jo YJ, Jang MY, Jung YK, Kim JH, Sim JB, Chun JY, Yoo SM, Han GJ,

- Min SG (2014). Effect of novel quick freezing techniques combined with different thawing processes on beef quality. *Korean J. Food Sci. An.* 34(6):777-783.
- Kim BS, Lee YE (2011). Effect of antioxidant on quality of ground beef during the refrigeration storage. *Korean J. Food Nutr.* 24(3):422-433.
- Lagerstedt A, Enfalt L, Johansson L, Lundstrom K (2008). Effect of freezing on sensory quality, shear force and water loss in beef *M. longissimus dorsi*. *Meat Sci.* 80(2):457-461.
- Leygonie C, Britz T, Hoffman L (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Sci.* 91(2):93-98.
- Lind ML, Harrison DL, Kropf DH (1971). Freezing and thawing rates of lambchops: Effects on palatability and related characteristics. *J. Food Sci.* 36(4):629-631.
- Londahl G (1997). Technological aspects of freezing and glazing shrimp. *Infotish Int.* 3:49-56.
- Lovatt SJ, James C, James SJ, Pham QT, Jeremiah LE (2004). Refrigeration and freezing technology. In: J. Werner Klinth (Ed.), *Encyclopedia of Meat Sciences*. Elsevier, Oxford. pp. 1131-1161.
- Lui Z, Xiong Y, Chen J (2010). Protein oxidation enhances hydration but suppresses water-holding capacity in porcine *longissimus* muscle. *J. Agric. Food Chem.* 58(19):10697-10704.
- Massaux C, Bera F, Steyer B, Sindic M (1999). High hydrostatic pressure freezing and thawing of pork meat: Quality preservation, processing times and high-pressure treatment advantages. *Adv. High Press. Biosci. Biotechnol.* pp. 485-488.
- Miller AJ, Ackerman SA, Palumbo SA (1980). Effects of frozen storage on functionality of meat for processing. *J. Food Sci.* 45(6):1466-1471.
- Mortensen M, Andersen HJ, Engelsen SB, Bertram HC (2006). Effect of freezing temperature, thawing and cooking rate on water distribution in two pork qualities. *Meat Sci.* 72(1):34-42.
- Ngapo TM, Babare IH, Reynolds J, Mawson RF (1999). Freezing rate and frozen storage effects on the ultra-structure of samples of pork. *Meat Sci.* 53(3):159-168.
- Nicholson F (1973). The freezing time of fish. Food and Agricultural Organization of the United Nations.
- Nilsson K, Ekstrand B (1995). Frozen storage and thawing methods affect biochemical and sensory attributes of rainbow trout. *J. Food Sci.* 60(3):627-630.
- Taher BJ, Farid MM (2001). Cyclic microwave thawing of frozen meat: Experimental and theoretical investigation. *Chem. Eng. Process.* 40(4):379-389.
- Wulf DM, Morgan JB, Sanders SK, Tatum JD, Smith GC, Williams S (1995). Effects of dietary supplementation of vitamin E on storage and case life properties of lamb retail cuts. *J. Anim. Sci.* 73(2):399-405.
- Zhou GH, Xu XL, Liu Y (2010). Preservation technologies for fresh meat- A review. *Meat Sci.* 86(1):119-128.

## Full Length Research Paper

# Antioxidant activity of Iranian barley grain cultivars and their malts

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Barley (*Hordeum vulgare L.*) belongs to the grass family *Poaceae* and is an ancient and important cereal grain crop. Whole grain products are recommended for healthy diets as being recognized sources of dietary fiber and antioxidant substances such as polyphenols and vitamin E. The current study was conducted to evaluate the antioxidant activity for 19 cultivars (Bahman, MB-82-12, Nosrat, Kavir, Torkman, Makoeei, Karoun, Valfajr, Reihane, Dasht, MB-42-4, Nik, Rihane-03, Sahra, Yosef, DD-10, Nimrooz, Fajr-30, Gorgan-4) of barely (*Hordeum vulgare L.*) grain and their malts. The Ferric reducing antioxidant power (FRAP) method was used to evaluate this activity. The Range of antioxidant activity in barely grain was ranged between 0.31-1.01 mg/kg and in malt was ranged between 0.64-3.34 mg/kg. The average antioxidant activity was significantly higher in malt (1.584±0.596 mg/kg) compared to barely grain (0.633 ±0.221 mg/kg)  $p \leq 0.001$ . Results of the current study show that Nosrat cultivar had significant difference from other cultivars of barley. But in malt products, MB-82-12 cultivar had significant difference with other malt products and had higher antioxidant activity. Finally, we recommend that, if the goal is to select the most antioxidant activity of barely and malt products, we preferred to use Nosrat cultivar of barley and MB-82-12 malt.

**Key words:** Antioxidant, barley cultivars, malt, ferric reducing antioxidant power (FRAP).

## INTRODUCTION

Free radicals contribute to more than one hundred disorders in human body. Free radicals due to environmental pollutants chemicals, toxins, radiation, etc causes depletion of immune system antioxidants, change in gene expression

and induce abnormal proteins (Pourmorad et al., 2006). Free radicals are controlled by enzymes such as medicinal plants, fruits, vegetables and seeds and can constitute an important source of antioxidants and they may be used to

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reduce oxidative damage and tissue injury (Amjad and Shafiqi, 2013). Many plants have anti-oxidative and pharmacological activities. Bioactive phenols, especially bioflavonoids are very interesting as antioxidants because of the ability to act as free radical scavenging, inhibition of hydrolytic and oxidative enzymes (Frankel, 1995). Some researchers suggest that the biological activity of these compounds is related to their antioxidant action (Gryglewski et al., 1987). Antioxidants play an important role in inhibition and radical scavenging, thus providing protection against diseases. Antioxidants inhibit many oxidation reactions caused by free radicals such as singlet oxygen, superoxide radicals, proxy radicals, hydroxyl radicals and proxy nitrate (Karthikumar et al., 2007).

The antioxidant properties of phenolic compounds in grains have been associated with the health benefits attributed to these crops and the value-added products derived from them. Antioxidants may play an important role in the chronic disease prevention by arresting oxidative damage caused by reactive oxygen species (ROS) to vital biomolecules such as DNA, lipids, and proteins (Hollman, 2001). One of the richest sources of phenolics among the grains is barley. In beer, for example, 70 to 80% of the phenolic constituents originate from malted barley while the remaining 20 to 30% come from the hops (Gerhauser 2005). The scavenging activity of barley phenolics against DPPH and ABTS were comparable to a synthetic antioxidant, butylated hydroxyl-toluene (BHT) (Ragaei et al., 2006). Barley (*Hordeum vulgare* L.) is one of the ancient cereal crops that currently have received increasing demands worldwide. It is considered as one of the most important cereals worldwide. It is the major cereal in many dry areas of the world and is vital for the livelihoods of many farmers. In Iran, it is mainly grown for grain and straw for small ruminants during winter, with green fodder sometimes used for winter grazing. Barley assumes fourth position in total cereal production in the world after wheat, rice, and maize. Barley is more productive under adverse environments than other cereals. Barley has also been used as animal fodder, as a source of fermentable material for beer and certain distilled beverages, and as a component of various health foods (Celus et al., 2006). It is used in soups and stews, and in barley bread of various cultures. Barley grains are commonly made into malt in a traditional and ancient method of preparation (Alazmani, 2015). Moreover, about two thirds of barley crop has been used for feed, one-third for malting and about 2% directly for food (Baik and Ullrich, 2008; Gupta et al., 2010). Barley grains were good source of phenols and contains very high amount of total phenolics. A wide range of phenolic antioxidant compounds has been found in barley such as benzoic and cinnamic acid derivatives, proanthocyanidins, flavonols, chalcones, flavones, flavanones, and amino phenolic compounds (Hernanz et al., 2001). They are present in free and bound form in cereals. Bound phenolics are ester-linked to cell-wall

polymers in the outer layers of kernel. Ferulic acid and its dehydromer derivatives is the major phenolic compound in cereals present mainly in bound form (Manach et al., 2004, Kim et al., 2007). Phenolics and other antioxidants found in cereals may act as free radical scavengers (Ragaei et al., 2006) and/or reducing agents, chelating pro-oxidant metals and singlet oxygen quenchers (Zielinski, 2002). Recently, no correlation was found between phenol and flavonoid contents and antioxidant activity in barley grain varieties (Sharifi et al., 2013). Malt and its products made from grains especially barley is considered as raw materials in industries with the highest conversion index and thus the greatest added value (Namaghi and Ghaboos, 2010). Over centuries, malting has been used for promoting enzymatic activity and decomposition of cell wall, softening the kernels, development of different aroma, flavor, and color, producing reduction sugars, and increasing the availability of vital nutrients of the grains. Malting is a biotechnologically complicated process including steeping, germination and drying germinated malt under temperature and humidity controlled conditions so that a friable nutrition product would be made (Gupta et al., 2010). During malting barley seeds are germinated to promote the mobilization of storage compounds process. Malting is influenced by various physicochemical factors including: barley variety, sulphur and nitrogen content, O<sub>2</sub> and CO<sub>2</sub> content, contents of carbohydrates, enzymes, antioxidants, proteins and lipids of barley and steeping and germination time (Eksiri et al., 2014). Today, malt has found a special application in food industry worldwide. Malt and its extract are used as sweeteners, flavorings, colorings a fermenting agent in malt vinegar and beer brewing, malt concentrate, maltodextrin, maltose syrup, infant formula, coffee malt, and some bakery products. Malt also shows medicinal properties including lowering blood sugar level, functioning against intestinal diseases, stimulation of lactating glands, anti-diarrhea, strengthening hairs and preventing them to become gray (Namaghi and Ghaboos, 2010). Antioxidants are not equally distributed in barley grain. p-Coumaric acid exhibited the lowest amount in the kernel center and rapidly increased towards outer layers such as lignified husk (Salomonsson et al., 1980). Phenolic acids are present mostly in the aleuronic layer and endosperm (Goupy et al., 1999). The highest amount of ferulic acid is found in cell walls of aleurone layer being rich in arabinoxylans. Natural antioxidants of cereals may act as free radical scavengers, reducing agents, potential complexes of pro-oxidant metals and singlet oxygen quenchers. Furthermore, many natural antioxidants present in barley exert wide – ranged biological effects including antibacterial antiviral anti-inflammatory, anti-allergic and anti – thrombotic effects and may also be involved in vasodilator actions (Cook and Sammon, 1996). Polyphenols identified in barley include anthocyanins, flavonols, phenolic acids catechins and proanthocyanidins. Antioxidants mostly play an important



role in malting and processing due to their ability to delay or prevent oxidation reactions and oxygen free radical reactions. Antioxidants such as sulfites, formaldehyde, or ascorbate can be added into the brewing process in order to improve beer flavor stability. Approximately 80% of phenolics of beer are derived from barley malt and the remaining comes from hops (Goupy et al., 1999). The phenolics in barley malting include polyphenols (benzoic and cinnamic acids derivatives), flavonoids, proanthocyanidins, tannins and aminophenolic compounds. All these compounds identified as non-enzymatic inhibitors of lipid peroxidation have been also known as having important antioxidant and antiradical properties (Eksiri et al., 2014). Thus the presence of natural antioxidants in malting barley and screening of malting barley varieties with the highest level of radical scavengers seem important to produce beers with high levels of antioxidant activity (Gupta et al., 2010). Recently, barely malt extract was found to prevent the reduction of antioxidant enzymes activities, to decrease the levels of malondialdehyde and carbonyl in liver and brain, and to improve total antioxidant capability in the D-galactose induced mouse aging model (Qingming et al., 2010). Malt contains various compounds of barley (endogenous phenolic compounds) from the malting process (Maillard reaction products) which can play significant role in malting and brewing through their antioxidant properties (Goupy et al., 1999). Munich-style malts melanoidin rich atmosphere is known to have antioxidant properties that are beneficial in stabilizing the taste of beer (Briggs, 1998). Malt processing releases inherent bound phenolic compound and creates new antioxidants through the maillard reaction in barley leading to increased antioxidant activity (Baba et al., 2014). Germinated barley can contain more than 45 mg/g dry weight as fat and linoleic acid as the main component (50-60%). During malting, a significant reduction in fat content could be observed, indicating rapid degradation. Free fatty acids produced during lipolysis can be done by autoxidation and lipoxygenase yields highly reactive peroxide aqueous deoxygenated. This hydro peroxidase enzyme can produce carbonyl compounds such as trans-2-nonenal (Moll and Moll, 1986). Two ways may be used naturally for oxidative deterioration of beer and malting method of optimizing control: protecting antioxidants present in barely (mainly polyphenones) and promotion of new products in antioxidants. Antioxidants are generally thought to play a significant role in malting and brewing due to their ability to delay or prevent oxidation reactions and oxygen free radical reactions (Zhao et al., 2008). Antioxidant compounds present in barley extracts are complex, and their activities and mechanisms would largely depend on the composition and conditions of the test systems. In order to better understand the antioxidant power of barley and malt, FRAP method (as a spectrophotometric method) was used to measure the antioxidant activity.

## MATERIALS AND METHODS

### Barley and malt samples

The barley cultivars were collected from the seed and plant improvement institute which included 19 Iranian barley cultivars: (Bahman, MB-82-12, Nosrat, Kavir, Torkman, Makoei, Karoun, Valfajr, Rihane, Dasht, MB-42-4, Nik, Rihane-03, Sahra, Yosef, DD-10, Nimrooz, Fajr-30, Gorgan-4). These cultivars were collected from the growing area of Iran and corresponding malts were studied. All barley samples (with germination capacity above 95%) were malted in the same way using standard malting conditions. The following technology was used for malt production from the tested grains: washing and steeping of grains ( $H_2O$   $T=17\pm 2^\circ C$ ) until moisture content in grains reached 38–40%. Then the grains were placed for germination. The kilning procedure occurred in six successive steps of heating:  $50^\circ C$  for 12 h,  $60^\circ C$  for 1.5 h,  $65^\circ C$  for 1.5 h,  $70^\circ C$  for 1.5 h,  $75^\circ C$  for 1.5 h and  $80^\circ C$  for 4 h till constant moisture content was achieved in the grains ( $5\pm 1\%$ ). Then the barley grains were held under warm and humid conditions for several days (germination) (Jones, 2005) and also to maintain embryo growth, enzymes synthesis and endosperm breakdown (Gupta et al., 2010). Finally they were dried under air current gradually increasing the temperature (kilning) for ensuring the product stability. This method is commonly used at the USDA Cereal Crops Research Unit described by Jones and Marinac (2000).

### Extraction procedure

Barley (or malt) was finely ground in a laboratory mill. Fifty grams of ground sample was extracted with 150 mL of water at  $45^\circ C$ . After a 1 h extraction, the weight was filled up to 200 g. Then the extract was filtered with Whatman No.1 filter paper. The crude extract was stored at  $-20^\circ C$  until used (MacGregor and Balance, 1980).

### Ferric reducing antioxidant power (FRAP) assay

Briefly, 900  $\mu L$  of the FRAP reagent (TPTZ 0.01 M:  $FeCl_3$  0.02 M: 0.1 M acetate buffer pH 3.6 (=1:1:10) was prepared daily, and 90  $\mu L$  of distilled water and 10  $\mu L$  of barley or malt extract were mixed and incubated at room temperature. Antioxidant activity was determined spectrophotometrically at 593 nm (UV visible spectrophotometer, GBC Cintra 40, Victoria, Australia) after 30 min. A series of concentrations of  $FeSO_4$  including 1000, 750, 500, 250 and 125  $\mu M$  were used for construction of calibration curve and were measured as described for sample solutions. All samples were performed in triplicate (Ozgen et al., 2006, Jannat et al., 2010).

### Statistical analysis

The experimental results were expressed as means  $\pm$  standard deviation (SD). SPSS version 18 was used to carry out the analysis of variance (ANOVA),  $P < 0.05$  values were regarded as significant.

## RESULTS AND DISCUSSION

Antioxidant activity of barley grain is not negligible. The results of the current study are shown in Table 1. The cultivar of barley had a significant influence on antioxidant efficiency. As shown in Table 1, malt of

**Table 1.** Antioxidant activity of different cultivars of barley grain and their malts.

Cultivar	Malt (Mean±SD) ( mgkg <sup>-1</sup> )	Barley (Mean±SD) ( mgkg <sup>-1</sup> )
Rihane-03	2.25±0.007	0.43±0.001
Makoeei	2.11±0.005	0.73±0.002
Mb-82-12	3.35±0.044	0.31±0.001
Gorgan-4	1.17±0.002	0.80±0.001
Mb-42-4	1.75±0.086	0.35±0.001
Karoun	0.65±0.001	0.71±0.004
Dasht	1.27±0.001	0.40±0.001
Nik	1.37±0.001	1.02±0.005
Fajr-30	1.48±0.017	0.56±0.001
Yosef	2.03±0.003	0.89±0.003
DD -10	0.98±0.001	0.32±0.001
Nosrat	1.12±0.002	1.02±0.002
Sahra	1.35±0.005	0.84±0.001
Kavir	1.65±0.002	0.59±0.001
Bahman	0.98±0.003	0.74±0.001
Torkman	1.89±0.003	0.53±0.001
Valfajr	1.31±0.001	0.47±0.001
Rihane	1.38±0.003	0.78±0.002
Nimrooz	2.01±0.001	0.55±0.001

Mb-82-12 cultivar had higher antioxidant activity than the others. On the other way, malt of Bahman and DD-10 cultivars varieties had lowest antioxidant activity and had significant difference with other cultivars. Most of the malts of the different barley cultivars had significant differences with each other, but Nik and Nosrat cultivars had no significant difference in antioxidant activities. In barley cultivars antioxidant activities, Nosrat cultivar had higher anti-oxidant activities and had a significant difference with other varieties. On the other hand, Mb-82-12 variety had lowest antioxidant activities. Differences in antioxidant activity between other barley varieties were significant. Majority of malts had higher antioxidant activities than their corresponding barleys. The increase of antioxidant activity could come from the development of such non-enzymatic browning products as Maillard products, which can also act as antioxidants, particularly melanoidins (Goupy et al., 1999; Yanagimoto et al., 2002; Yilmaz and Toledo, 2005; Osada and Shibamoto, 2006). In addition, hydrolytic enzymes can lead to the release of bound phenolic compounds, mainly the phenolic acids associated to lignin and arabinoxylans. Besides the synthesis of amylases, proteases and  $\alpha$ -glucanases causing polymer degradation, other hydrolytic enzymes can lead to the release of bound phenolic compounds, mainly the phenolic acids associated to lignin and arabinoxylans (Maillard et al., 1996; Maillard and Berset, 1995). Moreover, kilning leads to more friable tissues and probably allows better extraction of phenolic acids, mostly present in the outer layers of the grain (Maillard et al., 1996 and 2007). At the later stage of the drying process,

some observed increase in antioxidant activity could be attributable to the occurrence of antioxidant substances or phenolic compounds by thermal reactions such as non-enzymatic browning reactions (Yanagimoto et al., 2002; Yilmaz and Toledo, 2005; Osada and Shibamoto, 2006). Appearance of maillard reaction products during kilning has previously been proved. It has been shown that beers naturally contain products resulting from the thermal breakdown of carbohydrates or from the non-enzymatic browning reaction (Amadori compounds, enediols, enamines, enediamines, reductones and melanoidins (Moll and Moll, 1986). Duenas et al. (2009) showed that germination produced significant changes in flavonoids and non-flavonoid phenolic compounds of *Lupinus angustifolius* seeds. The results obtained indicate that germination modifies the quantitative and qualitative polyphenolic composition of lupin (*Lupinus angustifolius* L.) seeds during the different days of the process, with a significant increase of flavonoids. An increase in the antioxidant activity was also observed as a consequence of the process (Duenas et al., 2009). In fact, germination releases reducing sugars and amino acids. During the first steps of kilning, the water at the surface layers of the grain is removed (the humidity falls from 0.45 to 0.12 g/g) and the first intermediates of maillard reaction can be produced. Then, high temperatures and low humidity contents achieve the extension of the maillard reaction. Caramelization of sugars can also occur during the last steps of kilning, catalyzed by the low concentration of organic acids (Karakus, 1975). Ferulic acid reacts with maillard reaction

intermediates derived from glucose and proline at kilning temperatures, leading to higher antioxidant activity and an increase of antioxidant properties of maillard reaction products with heating time (Samaras et al., 2005).

## Conclusion

The present study demonstrated the influence of barley cultivar, and malting on antioxidant activity. The cultivar of barley has significant influence on antioxidant efficiency. Thus, this foundation can help the selection of barley cultivars, knowing their antioxidant efficiency and their phenolic composition. The choice of a cultivar must take into account two parameters: the antioxidant power of barley and its increase during malting. Antioxidant activity of barley seems to be somewhat related to the total phenolic content, particularly to the content of flavan-3-ols. Thus, it could be more judicious to choose a cultivar of barley showing a poly phenolic profile with the most antioxidative compounds. The influence of the kilning process was also demonstrated. During kilning, antioxidant activity increased, as well as the content of phenolic acids. However, more study is needed to demonstrate factors affecting the antioxidative capacity of barley and malt.

## Conflict of interests

The author(s) did not declare any conflict of interest.

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## REFERENCES

- Alazmani A (2015). Evaluation of yield and yield components of barley varieties to nitrogen. *Int. J. Agric. Crop Sci.* IJACS/2015/8-1/52-54.
- Amjad L, Shafiqi M (2013). Evaluation of antioxidant activity, phenolic and flavonoid content in *Punica granatum* var. Isfahan Malas flowers. *Int. J. Agric. Crop Sci.* 5(10):1133-1139.
- Baba WN, Rashid I, Shah A, Ahmad M, Gani A, Masoodi FA, Wani IA, Wani SM (2014). Effect of microwave roasting on antioxidant and anticancerous activities of barley flour. *J. Saudi Soc. Agric. Sci.* Advance online publication. doi:10.1016/j.jssas.2014.06.003
- Baik BK, Ullrich SE (2008). Barley for Food: Characteristics, Improvement, and Renewed Interest. *J. Cereal Sci.* 48: 233-242.
- Briggs DE (1998). *Malts and malting*, 1<sup>st</sup> ed. Blackie, London: Blackie Academic. pp.8-9.
- Celus I, Brijis K, Delcour JA (2006). The effects of malting and mashing on barley protein extractability. *Cereal Sci.* 44: 203-211.
- Cook NK, Sammon S (1996). Flavonoids: Chemistry, metabolism, cardioprotective effects and dietary sources. *J. Nutr. Biochem.* 7: 66-77.
- Duenas M, Hernandez T, Estrella I, Fernandez D (2009). Germination as a process to increase the polyphenol content and antioxidant activity of lupin seeds (*Lupinus angustifolius* L.). *Food Chem.* 117: 599-607.
- Eksiri M, Nateghi L, Haghverdi A (2014). The effects of physicochemical factors on malting (Review). *Adv. Environ. Biol.* 8(17): 1056-1063
- Frankel E (1995). Nutritional benefits of flavonoids. International conference on food factors: Chemistry and Cancer Prevention, Hamamatsu, Japan. Abstracts C6-2.
- Goupy P, Hugues M, Boivin P, Miot MJ (1999). Antioxidant composition and activity of barley (*Hordeum vulgare*) and malt extracts and of isolated phenolic compounds. *J. Sci. Food Agric.* 79: 1625–1634.
- Gryglewski RJ, Korbut R, Robak J (1987). On the mechanism of anti-thrombotic action of flavonoids. *Biochem. Pharmacol.* 36:317-321.
- Gupta M, Abu-Ghannam N, Gallagher E (2010). Barley for brewing: characteristic changes during malting, brewing and applications of its by-products. *Compr. Rev. Food Sci. Food Saf.* 9:318-328.
- Hernanz D, Nuñez V, Sancho AI, Faulds CB, Williamson G, Bartolomé B, Gómez-Cordovés C (2001). Hydroxycinnamic acids and ferulic acid dehydrodimers in barley and processed barley. *J. Agric. Food Chem.* 49: 4884–4888.
- Hollman PCH (2001). Evidence for health benefits of plant phenols: local or systemic effects? *J. Agric. Food Chem.* 81:842-852
- Jones BL (2005). Endoproteases of barley and malt. *Cereal Sci.* 42: 139-156.
- Jannat B, Oveis MR, Sadeghi N, Hajimahmoodi M, Behzad M, Choopankari E, Behfar AA (2010). Effects of Roasting Temperature and Time on Healthy Nutraceuticals of Antioxidants and Total Phenolic Content in Iranian Sesame Seeds (*Sesamum indicum* L.). *JEHSE.* 7:97-102.
- Jones BL, Marinac LA (2000). Purification and partial characterization of a second cysteine proteinase inhibitor from ungerminated barley (*Hordeum vulgare* L.). *Agric. Food Chem.* 48:257-264.
- Karakus M (1975). Étude biochimique & technologique des réactions de brunissement au maltage. thèse de doctorat enieur université e de nancy i. Book, Archival Material.
- Karthikumar S, Vingneswari K, Jegatheesan K (2007). Screening of antibacterial and antioxidant activities of leaves of *Eclipta prostrata* (L). *Sci. Res Essays* 2(4):101-104.
- Kim M-J, Hyun J-N, Park J-C, Kim JG, Lee S-J, Chun S-C, Chung I-M (2007). Relation between phenolic compounds, anthocyanins content and antioxidant activity in colored barley germplasm. *J. Agric. Food Chem.* 55: 4802–4809.
- MacGregor AW, Balance D (1980). Quantitative determination of  $\alpha$ -amylase enzymes in germinated barley after separation by isoelectrofocusing. *J. Inst. Brew.* 86:131-133.
- Maillard MN, Berset C (1995). Evolution of Antioxidant activity during kilning: Role of insoluble bound phenolic acids of barley and malt. *J. Agric. Food Chem.* 43: 1789–1793.
- Maillard MN, Billaud C, Chow YN, Ordonaud C, Nicolas J (2007). Free radical scavenging inhibition of polyphenoloxidase activity and cooper chelating properties of model Maillard systems. *LWT - Food Sci. Technol.* 40:1434-1444.
- Maillard MN, Soum MH, Boivin P, Berset C (1996). Antioxidant activity of barley and malt: Relationship with phenolic content. *LWT - Food Sci. Technol.* 29: 238-244.
- Manach C, Scalbert A, Morand C, Rémésy C, Jiménez L (2004). Polyphenols: Food sources and bioavailability. *Am. J. Clin. Nutr.* 79: 727–747.
- Moll N, Moll M (1986). Additives and endogenous antioxidants countering the oxidation of beer. *Dev. Food Sci.* 12:97-140.
- Namaghi AR, Ghaboos SH (2010). Malt & non-alcoholic malt drink, Iran, pp. 14-16.
- Osada Y, Shibamoto T (2006). Antioxidative activity of volatile extracts from Maillard model systems. *Food Chem.* 98:522-528.
- Pourmorad F, Hosseinimehr SJ, Shahabimajid N (2006). Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants. *Afr. J. Biotechnol.* 5(11):1142-1145.
- Qingming Y, Yianhui P, Weibao K, Hong Y, Yidan S, Li Z, Yanan Z, Lan D, Guoan L (2010). Antioxidant activities of malt extract from barley (*Hordeum vulgare* L.) toward various oxidative stress *in vitro* and *in vivo*. *Food Chem.* 118:84-89.
- Ragaei S, Abdel-Aal E-SM, Noaman M (2006). Antioxidant activity and nutrient composition of selected cereals for food use. *Food Chem.*

98:32-38.

Salomonsson AC, Theander O, Aman P (1980). Composition of normal and high-lysine barley. Swedish J. Agric. Res. 10(1): 11-16.

Samaras TS, Gordon MH, Ames JM (2005). Antioxidant properties of malt model systems. J. Agric. Food Chem. 53(12): 4945-4983.

Sharifi M, Zadeh E, Ali M (2013). Antioxidant activity, phenol and flavonoid contents of eleven Iranian barley grain varieties (*Hordeum vulgare* L.). World. Sci. J. 1 (5): 88-94.

Yanagimoto K, Lee KG, Ochi H, Shibamoto T (2002). Antioxidative activity of heterocyclic compounds formed in Maillard reaction products. Int. Congr. Ser. 1245:335-340.

Yilmaz Y, Toledo R (2005). Antioxidant activity of water-soluble Maillard reaction products. Food Chem. 93:273-278.

Zhao H, Fan W, Dong J, Lu J, Chen J, Shan L, Lin Y, Kong W (2008). Evaluation of antioxidant activities and total phenolic contents of typical malting barley varieties. Food Chem. 107:296-304.

Zielinski H (2002). Low molecular weight antioxidants in the cereal grain: A review. Pol. J. Food Nutr. Sci. 11:3-9.

Ozgen M, Reese RN, Tulio AZ, Scheerens JC, Miller AR (2006). Modified 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) method to measure antioxidant capacity of selected small fruits and comparison to ferric reducing antioxidant power (FRAP) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) methods. J. Agric. Food Chem. 54: 1151-1157.





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