

Accepted Manuscript

Impact of ultrasound and blanching on functional properties of hot-air dried and freeze dried onions

F. Ren, C.A. Perussello, Z. Zhang, J.P. Kerry, B.K. Tiwari



PII: S0023-6438(17)30623-0

DOI: [10.1016/j.lwt.2017.08.053](https://doi.org/10.1016/j.lwt.2017.08.053)

Reference: YFSTL 6475

To appear in: *LWT - Food Science and Technology*

Received Date: 8 June 2017

Revised Date: 14 August 2017

Accepted Date: 19 August 2017

Please cite this article as: Ren, F., Perussello, C.A., Zhang, Z., Kerry, J.P., Tiwari, B.K., Impact of ultrasound and blanching on functional properties of hot-air dried and freeze dried onions, *LWT - Food Science and Technology* (2017), doi: 10.1016/j.lwt.2017.08.053.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

**Impact of ultrasound and blanching on functional properties of hot-air dried and freeze
dried onions**

Ren, F.^{1,2}, Perussello, C. A.^{1*}, Zhang, Z.¹, Kerry, J. P.², Tiwari, B. K.¹

¹Food Chemistry and Technology Department, Teagasc Food Research Centre, Ashtown,
Dublin 15, Ireland.

²University College Cork, Western Road, Cork, Ireland.

*Corresponding author: camila.perussello@teagasc.ie, +353 761111754.

1 **Impact of ultrasound and blanching on functional properties of hot-air dried and**
2 **freeze dried onions**

3
4 **ABSTRACT:** The aim of this study was to investigate the effect of ultrasonic
5 treatment and blanching prior to hot-air drying and freeze drying of onions on the
6 retention of bioactive compounds (total phenolics, total flavonoids, and quercetin).
7 Onion slices were treated either with ultrasound at 20 kHz and different amplitude
8 levels (24.4-61 μm) for 1, 3 and 5 min or with blanching using hot water at 70°C for
9 1, 3 and 5 min. The ultrasound treatment improved the retention of bioactive
10 compounds (especially quercetin) and accordingly the antioxidant activity in onion
11 slices dried either by freeze drying or hot-air drying. This is ascribed to the
12 destruction of the original tissue structure by ultrasound and thus higher extraction
13 ability of the studied phytochemicals. Comparing ultrasound treated samples, freeze
14 dried onions had a higher retention of bioactive compounds than hot-air dried ones.
15 Blanched and ultrasound treated dried onions exhibited similar colour change.
16 Therefore, ultrasound treatment is a potential alternative to conventional blanching
17 before drying of onion slices.

18 **Keywords:** Ultrasound treatment; Thermal blanching; Antioxidant activity; Drying;
19 Colour.

20
21 **1. INTRODUCTION**

22

23 Dried onions are found in different forms – flaked, minced, chopped and
24 powdered – of extensive demand in several parts of the world (Sarsavadia, Sawhney,
25 Pangavhane, & Singh, 1999).

26 Sonication is a promising non-thermal technology in the food industry (Tiwari et
27 al., 2010). Ultrasound treatments (US treatments) are used to induce desirable
28 chemical and physical changes in foods and can support several processes, such as
29 drying, osmotic dehydration, extraction, mixing, emulsification, filtration,
30 crystallization, thawing and freezing (Marcuzzo, Peressini, Debeaufort, & Sensidoni,
31 2010). Ultrasonic waves cause rapid compressions and expansions to plant cells,
32 which leads to the formation of bubbles in the sonicated sample and its surroundings.
33 The resulting rapid and short pressure and temperature shifts in the product leads to
34 changes of viscosity and surface tension, destroying cell walls, forming microscopic
35 channels and free radicals, and producing sonochemicals. Scientific evidence exists to
36 support both the positive and the negative impacts of ultrasound treatment on the
37 retention of bioactive compounds in various fruit and vegetables, although the
38 particular effect depends on the process conditions and specificity of the material
39 involved (Mieszczakowska-Frać, Dyki, & Konopacka, 2016). Advantages of power
40 ultrasound include reduction in processing time, the effective removal of occluded
41 oxygen in juices, and lower energy consumption (Knorr, Zenker, Heinz, & Lee,
42 2004).

43 The responses of plants to abiotic stresses, such as US, associated with the
44 production of stress signalling molecules (i.e. reactive oxygen species – ROS) activate

45 the expression of genes involved on the primary and secondary metabolism of the
46 plant (Jacobó-Velázquez, González-Agüero, & Cisneros-Zevallos, 2015). These genes
47 are associated with an increase in the activity of enzymes related with the biosynthesis
48 of secondary metabolites and with the accumulation of secondary metabolites
49 (Jacobó-Velázquez et al., 2015). For this reason, US can be used as an approach to
50 increase the extractability of bioactive compounds (Nowacka & Wedzik, 2016), for
51 instance, found a 12.5% higher extractability of carotenoid from carrots after the
52 application of US at 21 kHz. Ultrasound has also shown higher extraction rates of
53 phenolic compounds from carrot pomace and strawberries (Jabbar et al., 2015). Power
54 ultrasound has also potential as a means of preservation due to the microbial
55 inactivation ascribed to cavitation, as the resulting pressure shifts contributes to cell
56 disruption. Ancillary chemical effects, such as the formation of free radicals as a
57 consequence of the sonochemical reaction, also contribute to the microbial cell
58 disruption (Kadkhodae & Povey, 2008).

59 The most popular drying methods for onions are hot-air drying and freeze drying.
60 Hot-air drying involves exposure of the product to a continuously flowing hot air
61 stream. It produces dehydrated products with a shelf life of up to one year, but their
62 quality is usually lower than that of the original foodstuff (Ratti, 2001). Freeze-drying
63 is based on dehydration by sublimation of water from a frozen product. Due to the
64 absence of liquid water and the low temperatures required for freeze drying, most of
65 the deterioration and microbiological reactions are retarded resulting in a final product
66 of high quality (Rawson et al., 2011). However, the quality of a dehydrated product

67 depends also on the pre-treatments employed before drying (Negi & Roy, 2000).
68 Hot-water blanching (heating of a product with hot water for a short period) has also
69 been reported to reduce drying time up to a certain operation temperature. Similarly to
70 other thermal processes, blanching affects the concentration of some bioactive
71 compounds in vegetables (Rawson et al., 2011).

72 Given the possible detrimental effects of blanching on the quality of onions, it is
73 necessary to develop alternative pre-treatments to replace blanching. Despite power
74 ultrasound has been extensively reviewed in fruits, its effects on quality parameters
75 have not been studied in thin sliced onions.

76 The present study investigated the effect of ultrasonic and blanching
77 pre-treatments prior to hot-air drying and freeze drying on the retention of bioactive
78 compounds (total phenolics, total flavonoids, and individual flavonoids), colour and
79 antioxidant activity of onions.

80

81 **2. MATERIALS AND METHODS**

82 **2.1 Chemicals**

83

84 Gallic acid, methanol, acetonitrile, ethanol, potassium acetate, aluminium chloride
85 (AlCl_3), ferric chloride, 2,2-Diphenyl-1-picrylhydrazyl (DPPH),
86 2,4,6-tripyridyl-s-triazine (TPTZ), hydrogen chloride (HCl),
87 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), and trifluoroacetic
88 acid (TFA) were obtained from Sigma (Sigma Aldrich, Arklow, Ireland). Quercetin

89 4'-glucoside (Q 4' G), quercetin 3,4' diglucoside (Q 3,4' D) and quercetin (Q)
90 standards were purchased from Extrasynthese (Geney Cedex, France).

91

92 **2.2 Sample preparation**

93

94 Fresh organic onions were obtained from the Kinsealy Systems field trial carried
95 out at Teagasc, Kinsealy (53° 25N, 6° 10W), Dublin, Ireland and stored at 4°C for a
96 maximum of 24 h prior to analysis. After hand-peeling, onions were vertically sliced
97 (5 mm thickness) using a Berkel 800 meat slicer (Berkel company, Indiana, USA).

98

99 **2.3 Ultrasound and blanching pre-treatments**

100

101 One kg of fresh organic onion slices (thickness of approximately 1 cm) were
102 obtained from 10 skin-peeled onion bulbs (variety: Hyskin). In each treatment, 50 g of
103 onion slices were mixed with 100 mL of distilled water at 70°C in a 200 mL beaker.

104 Ultrasound (20 kHz) was irradiated to 50 g of onion slices mixed with 100 mL of
105 water at 70°C with an ultrasonic probe (Ø19 mm) connected to an ultrasonic generator
106 (VC 1500, Sonics and Materials Inc., USA). The energy input was controlled by
107 setting the amplitude of the sonicator probe. Extrinsic parameters of amplitude (power
108 output of 40%, 60% and 80%, equivalent to 24.4, 42.7 and 61 µm) and processing
109 time (1, 3 and 5 min) were varied with pulse duration of 5 s on and 5 s off. The
110 ultrasound probe was submerged to a depth of 25 mm into the sample. All treatments

111 were carried out in triplicate. The ultrasound densities ranged between 0.06 and 0.59
112 W/mL.

113 For the blanching pre-treatment, carried out alternatively to the-US treatment, 50
114 g of onion slices were mixed with 100 mL of distilled water at 70°C for 1, 3 and 5
115 min. All treatments were carried out in triplicate.

116

117 **2.4 Preparation of extracts from dried onions**

118

119 Control (fresh), sonicated and blanched slices were either freeze-dried or hot-air
120 dried. Hot-air drying of sonicated, blanched and untreated (control) samples was
121 carried out in a laboratory scale hot-air drier (SG9606333, Gallenkamp, UK) at 60°C
122 and 0.3 m/s for 8 h. Pre-treated and control samples of 50 g were placed in a
123 perforated basket (300 x 400 mm; perforation size of 5 x 5 mm), which was inserted
124 in the drying chamber. Each sample was dried separately. Freeze-drying was carried
125 out in a Cuddon freeze-drier (FD80, Cuddon Freeze Dry, Blenheim, New Zealand) at
126 0.064 mbar for 72 h. After freeze dried or hot-air dried, the samples were
127 vacuum-packed in polypropylene bags and stored at -20°C until analysis.

128 The leaching water resulting from the ultrasound and blanching pre-treatments
129 were also freeze-dried or hot-air dried, according to the drying method selected for the
130 onion slices. The dry weights were used to calculate the transfer of material from the
131 onions into the cooking water. For this, the dried onions were blended by a kitchen
132 blender (Kenwood Ltd, Havant, UK). Then, 1 g of the blended sample was mixed

133 with 10 mL of methanol (80%) and homogenised at 24,000 rpm using an Omni-prep
134 multi-sample homogeniser (Omni International, USA). The homogenized sample
135 suspension was shaken overnight with a V400 Multitude Vortexer (Alpha
136 laboratories, North York, Canada) at 1500 rpm at room temperature. The sample
137 suspension was centrifuged (MSE Mistral 3000i, Sanyo Gallenkamp, Leicestershire,
138 UK) at 3000 g for 15 min and immediately filtered through 0.22 µm
139 polytetrafluoroethylene filters. The extracts were kept at -20°C until further analysis.

140

141 **2.5 Analysis of total phenolics (TPC)**

142

143 The total phenolic content was determined using the Folin-Ciocalteu method
144 with slight modifications (Singleton, Orthofer, & Lamuela-Raventós, 1999) using a
145 spectrophotometer (Shimadzu UV-1700, Shimadzu Corporation, Kyoto, Japan) at 735
146 nm. Aqueous gallic acid (10-400 mg/L) was used as standard. The results were
147 expressed as gallic acid equivalents per dry weight of sample (mg GAE/g DW).

148

149 **2.6 Analysis of total flavonoid content (TFC)**

150

151 The total flavonoid content was determined by the method described by Lin and
152 Tang (2007) using a spectrophotometer at 415 nm. Quercetin (Q) was used to build
153 the standard calibration curve. The total flavonoid content was expressed as

154 milligrams of quercetin equivalents per gram of dry weight (DW) (mg quercetin/g
155 DW).

156

157 **2.7. Analysis of antioxidant activity**

158

159 **2.7.1 Ferric Reducing Antioxidant Power (FRAP) assay**

160

161 The FRAP assay was carried out based on the method by Stratil et al. (2006) with
162 slight modifications. The FRAP solution was freshly prepared on the day of use by
163 mixing acetate buffer (pH 3.6), ferric chloride solution (20 mM) and TPTZ solution
164 (10 mM TPTZ in 40 mM HCl) in a proportion of 10:1:1, respectively. Subsequently,
165 the FRAP solution was heated, while protected from light, until a temperature of 37°C.
166 Appropriate dilutions of onion extracts were prepared using methanol. The sample
167 extract (100 µL), or blank (100 µL methanol) and Trolox standard dilutions (100 µL
168 Trolox of appropriate concentration) were mixed with 900 µL of FRAP solution in a
169 micro-centrifuge tube. The tubes were stirred and left to rest at 37°C for 40 min, and
170 the absorbance was measured at 593 nm using a spectrophotometer. The antioxidant
171 activity of the samples was expressed in mg of Trolox equivalent per gram of dry
172 weight sample (mg Trolox/g DW).

173

174 **2.7.2 DPPH Antioxidant Power Assay**

175

176 The DPPH (2, 2-diphenylpicrylhydrazyl) scavenging activity assay was
177 performed following the method described by Goupy et al. (1999). DPPH was
178 dissolved in methanol to a concentration of 0.238 mg/mL in a conical flask. The
179 reagent was prepared 2 hours prior to use, to ensure that the DPPH was fully
180 dissolved and stabilised. The flask containing the DPPH solution was covered with
181 aluminium foil to protect it from the light and stored in a refrigerator. For the actual
182 measurements, a 1:5 dilution of the DPPH stock was prepared using 10 mL of the
183 stock and making up to the 50 mL with methanol. Trolox (1-10 µg/mL) dissolved in
184 methanol in appropriate dilutions were used to build the standard curve. This
185 experiment was carried out in three replicates for both samples and standard. In each
186 replicate, 500 µL from the appropriately diluted sample extract was added to 500 µL
187 of DPPH solution. Experiments were carried out to determine the exact dilutions
188 required. In the control, 500 µL of methanol was added in place of the sample extract
189 with an equal volume of DPPH solution. As for the blank, 500 µL of sample extract
190 was mixed with 500 µL of methanol. The absorbance was measured at 515 nm in a
191 spectrophotometer. The radical scavenging activity was expressed in terms of mg of
192 Trolox equivalent per gram of dry weight (mg Trolox/g DW).

193

194 **2.8 HPLC analysis of the extracts**

195

196 Reversed phase high performance liquid chromatography (RP-HPLC) of the
197 filtered sample extracts was carried out according to the method of Tsao and Yang

198 (2003). Flavonols were separated on a ZORBAX SB-C18 column (4.6 mm x 150 mm,
199 5 µm particle size, Part no. 883975-902). The mobile phase consisted of HPLC grade
200 water with 0.05 % trifluoroacetic acids (TFA) (A) and acetonitrile with 0.05 % TFA
201 (B). The gradient involved a linear increase/decrease in the amount of solvent B in A,
202 which was set as follows (% B): 0-15 min, 12-21 %; 15-25 min, 21-100 %; 25-35 min,
203 100-12 %. The flow rate was 1 mL/min. Samples of 10 µL were injected into the
204 column and the separation took place at 30°C. The data was presented in the
205 SHIMADZU EZ START Version 7.3 software. The identification of compounds was
206 achieved by comparing their retention times and UV-Vis spectra with those of
207 authenticated quercetin standard, and the UV absorbance was measured at 360 nm.
208 Quercetin and quercetin glucoside concentrations were calculated against authentic
209 calibration standards (quercetin 4' glucoside, quercetin 3,4' diglucoside and
210 quercetin).

211

212 **2.9 Colour**

213

214 Three onion slices were randomly selected from fresh and dried samples to
215 determine colour at both sides (internal and external) of each slice using a colorimeter
216 (D25A DP-9000, Hunter Lab, Reston, VA, USA). The samples were evaluated for
217 colour (L^* , a^* and b^*) at room temperature. L^* represents luminosity and ranges from
218 black at 0 to white at 100. The chromaticity coordinate a^* indicates red when positive
219 and green when negative, and b^* indicates yellow when positive and blue when

220 negative (Doymaz, Tugrul, & Pala, 2006). The colour change, ΔE was calculated by
221 Eq. 1 (Vega-Gálvez et al., 2012):

222

$$223 \Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (1)$$

224

225 where L_0^* , a_0^* , and b_0^* are the values for fresh onion samples.

226

227 **2.10 Statistical analysis**

228

229 All experiments were carried out in triplicate and average values were reported as
230 means \pm standard deviation. The experimental data were statistically analysed using
231 the software SAS V.9.1 (SAS Institute, NC, USA). The Tukey-Kramer test was
232 applied for multiple comparisons among means at a 95% significance level ($p < 0.05$).

233

234 **3. RESULTS AND DISCUSSION**

235 **3.1 Change of total phenolic content**

236

237 The ultrasound and blanching treatments influenced the total phenolic content
238 (TPC) of onion slices (Table 1). Blanching applied for 1 min and ultrasound applied
239 for 1-3 min in general increased the TPC of dried onions. After 3 min of ultrasound
240 treatment at 42.7 μm and 61.0 μm , for example, there was a 17%-21% TPC increase
241 in freeze dried onions ($p < 0.05$). Samples treated by ultrasound at 61.0 μm for 1 min

242 followed of hot-air drying had a 10% increase ($p<0.05$) compared to the untreated
243 dried samples. The application of sonication techniques to assist in the extraction of
244 bioactive compounds is in fact widely reported (Keenan et al., 2012). On the contrary,
245 blanched freeze dried (BFD) and blanched hot-air dried (BHD) (3 and 5 min) samples
246 had lower retention of phenolics compared to the control ($p<0.05$). Turkmen, Sari,
247 and Velioglu (2005) also reported that blanching decreased the total phenolics in
248 squash, peas and leek.

249 Samples subjected to UFD (ultrasound + freeze drying) at 24.4 μm for 3 min and
250 UHD (ultrasound + hot-air drying) at 61.0 μm for 1 min resulted in greater retention
251 of phenolics than samples blanched for the same time. Also, blanching caused
252 phenolics to leach into the cooking water nearly 1-3 times more than during the
253 ultrasound treatment (Table 1). In agreement with this finding, Rawson et al. (2011)
254 reported higher retention of carotenoids and polyacetylenes in dried carrots subjected
255 to a 10 min-pre-treatment with a US-probe under pulsed mode than in dried carrots
256 blanched at 80°C for 3 min.

257 However, the relatively high temperature and longer holding time related to the 5
258 min-ultrasound treatment led to more severe oxidative and thermal degradation than
259 the other ultrasound treatments. The main mechanism involved in the loss of
260 phenolics during US treatment might be the formation of microchanel during
261 cavitation, which facilitate the transport of food constituents, especially soluble
262 nutrients (Mothibe, Zhang, Nsor-atindana, & Wang, 2011). In fact, Opalić et al. (2009)
263 reported that prolonged US pre-treatment in samples with the same geometry led to a

264 decrease in total phenolics and flavonoids and accordingly in the antioxidant capacity
265 of dried apples. The degradation trend during ultrasonic processing may be also
266 related to the formation of free radicals, resulting in a potential increase in the
267 oxidation pathways (Pétrier, Combet, & Mason, 2007). The degradation related to the
268 some of the US treatments may point to additional contributory factors. The
269 ultrasound probe had direct contact with the sample, with the vessel opened to the
270 atmosphere (i.e. it was not a closed system). Therefore, oxidation could freely occur
271 at the liquid/atmosphere interface during processing. This effect would be increased in
272 samples processed for longer periods (i.e. 5 min).

273

274 **3.2 Change of total flavonoids content**

275

276 There was a significant difference of TFC ($p < 0.05$) between ultrasound-treated
277 and blanched onions after drying compared to dried samples without pre-treatment,
278 considering either freeze-dried or hot-air dried (Table 1).

279 TFC in dried (freeze drying and hot-air drying) onion slices treated with
280 ultrasound for 1-3 min in general increased compared to the control dried samples.
281 Lower ultrasound amplitudes (24.4 μm) combined with freeze drying and higher
282 amplitudes (61 μm) combined with hot-air drying resulted in better retention of TFC
283 compared to other ultrasound treatment conditions or dried samples not submitted to
284 pre-treatment (Table 1). Such increase in the retention of TFC may arise from an
285 enhanced extractability of the compounds. Improved extraction efficiency following

286 sonication has been attributed to the propagation of ultrasound pressure waves,
287 induced cavitation and high shear forces resulting in increased mass transfer (Rawson
288 et al., 2011). There was also a significantly ($p<0.05$) higher retention of flavonoids in
289 UFD (24.4 μm for 3 min) and UHD (61.0 μm for 1 min) than BHD (1, 3 and 5 min)
290 samples. Regarding blanching, as higher the process time, lower was the retention of
291 flavonoids.

292

293 **3.3 Change of antioxidant activity during pre-treatment**

294

295 The antioxidant activity of pre-treated and untreated (control) dried onion slices
296 are presented in Table 1. Sonicated samples processed at the highest amplitude (61 μm)
297 for the longest time (5 min) and then freeze-dried as well as sonicated samples
298 processed at the lowest amplitude (24.4 μm) for 5 min and then hot-air dried had the
299 lowest ($p<0.05$) antioxidant activity. Generally, onions sonicated at lower amplitudes
300 followed of freeze drying had the highest antioxidant activity (FRAP and DPPH),
301 while longer US-times reduced the antioxidant activity (Table 1).

302 The DPPH and FRAP values were similar and indicate that blanching generally
303 resulted in lesser preservation of antioxidant compounds compared to fresh and
304 sonicated samples. The exception was the 1 min-blanching, which resulted in
305 enhanced antioxidant activity. Some studies have suggested that blanching is
306 generally regarded as being destructive to antioxidant components (Krishnaswamy &
307 Raghuramulu, 1998). On the contrary, Halvorsen et al. (2006) reported increased

308 antioxidant activity for several vegetables such as carrots, spinach, mushroom,
309 asparagus, broccoli and cabbage after thermal treatment. Dewanto, Xu and Liu (2002)
310 found similar results in thermally processed tomatoes compared with fresh controls.
311 These authors hypothesised that higher antioxidant activities may be related to an
312 increase in extractability of antioxidant components following thermal processing.

313

314 **3.4 Changes of quercetin and quercetin glucosides**

315

316 The levels of the 3 major quercetins – quercetin 3,4'diglucoside (Q 3,4' D),
317 quercetin 4'glucoside (Q 4' G), and quercetin (Q) – in dried onions are presented in
318 Fig.1-3.

319 In general, the retention levels of Q 3,4' D and Q for US-freeze dried and US-hot
320 air dried samples were higher compared to the samples dried without any
321 pre-treatment. This can be ascribed to the increased extractability induced by
322 cavitation of US-treated samples (Rawson et al., 2011).

323 In BFD and BHD onions slices (1 min), the retention levels of Q were higher
324 compared to the control ($p < 0.05$). Blanching in fact does not always result in the
325 destruction of bioactive compounds. In some cases, thermal treatments can induce the
326 formation of novel compounds and improve the antioxidant capacity (Xu & Chang,
327 2008). Bunea et al. (2008) suggested that the increase in the concentrations of certain
328 bioactive compounds after thermal treatment may be explained either by their better
329 release from the food matrix as a result of breakdown of supramolecular structures

330 containing functional groups or their thermal stability. However, in BFD and BHD
331 samples (3 and 5 min), the retention levels of Q were lower compared to the control
332 ($p<0.05$). This is most likely due to the relatively high temperatures required for
333 blanching (70°C sustained for 3-5 min), which could lead to oxidative and thermal
334 degradation (Rawson et al., 2010).

335 Regarding the freeze drying, the ultrasound treatment at 24.4 μm for 3 min
336 resulted in significantly higher retention levels of Q 3,4' D and Q compared to BHD
337 (1-5 min) samples. With regard to the hot air drying, there were significantly higher
338 retention levels of Q 4' G and Q after US treatment at 61.0 μm for 1 min compared to
339 BHD (1-5 min) samples.

340

341 **3.5 Phenolic compounds and antioxidant activity in water**

342

343 Blanching retained greater amounts of phenolic compounds than ultrasound
344 ($p<0.05$). The losses could be attributed to water soluble phenolics leaching into the
345 cooking water as well as breakdown of phenolics during thermal processing. These
346 significant losses could be attributed to water soluble phenolics leaching and
347 transferred into the cooking water as well as breakdown of phenolics during thermal
348 processing, which rendered water a good source of dietary phenolics (Table 2).

349 However, degradation of phenolics in onion slices may be a bigger problem than
350 leaching. The percentage loss of phenolics undergoing degradation during the
351 US-treatment was higher than the percentage loss to the cooking water. These results

352 suggest that the degradation of phenolics after sonication was greater than the losses
353 due to leaching. Some authors have indicated that pressure-cooking enhanced the
354 antioxidant composition and palatability of vegetables (Xu & Chang, 2009). However,
355 higher power could result in greater degradation (Hiemori, Koh, & Mitchell, 2009).

356

357 **3.6 Flavonoids in water**

358

359 The total flavonoid content in the cooking water revealed a trend similar to that
360 described for the TPC (Table 2). The flavonoid losses could be a result of degradation
361 or decomposition of flavonoids (Ioannou, Hafsa, Hamdi, Charbonnel, & Ghoul, 2012).
362 The ultrasound treatment resulted in a higher percentage of flavonoids being degraded
363 than retained in the cooking water ($p < 0.05$). There was a transfer of especially Q 3,4'
364 D and Q 4' G from onions to water. This suggests that the decrease of flavonoid
365 during ultrasound was predominantly caused by breakdown of flavonoids rather than
366 their leaching. Higher ultrasound amplitudes and longer time resulted in greater
367 leaching of flavonoids.

368

369 **3.7 Quercetin and its glucosides in water**

370

371 The amounts of quercetin 3,4'diglucoside and quercetin 4' glucoside were also
372 measured in water after ultrasound and blanching treatments (Table 2). In the
373 US-treatment water, the quercetin 4'glucoside fraction was greater than the quercetin

374 3,4'-diglucoside one. Hirota, Shimoda, and Takahama (1998) observed that the
375 monoglucoside derivative was oxidized more rapidly than its diglucoside form during
376 cooking, and that the difference in the stability between mono and diglucoside was
377 due to the presence or absence of a hydroxyl group at the C-3 position in the
378 glucosides. As the antioxidant power of flavonols substantially depends on the
379 catechol group in the B-ring and on the 3-hydroxyl group (Rodrigues, Pérez-Gregorio,
380 García-Falcón, & Simal-Gándara, 2009), the monoglucoside is likely to have a higher
381 antioxidant capacity than the diglucoside, since in the latter these two basic functions
382 are blocked. In this work, there was a lower content of flavonols in water, which was
383 however enriched with antioxidant monoglucoside forms.

384 Free quercetin was found in the onion slices (Table 2) but only in very small
385 amounts in the cooking water (Table 2), which may correspond to its poor solubility
386 in water and/or stronger binding to plant structures than its glycoside forms. Quercetin
387 was not detected in water after the 5 min-ultrasound treatment, indicating that this
388 compound is not prone to leaching.

389

390 **3.8 Antioxidant activity in water**

391

392 The blanching water had high antioxidant (Table 2), especially for the 1
393 min-treatment, followed by 3 min. The cooking water from US-treated onions had
394 low values of antioxidant activity according to both assays. The sum of antioxidant
395 activity of the cooked onion and cooking water is different from the antioxidant

396 activity of fresh samples, which may suggest losses in the antioxidant activity due to
397 breakdown or degradation of antioxidant compounds.

398

399 **3.9 Effect of ultrasound and blanching on colour**

400

401 Colour has a major impact on the acceptance of a product by the consumer (Kalt,
402 2005). Fresh onions were characterized by high luminosity ($L^* = 74.24 \pm 2.15$), with
403 a tendency to green and yellow ($a^* = -6.23 \pm 0.53$ and $b^* = 22.79 \pm 2.8$, respectively)
404 (Table 3). The L^* of dried samples ranged from 58.3 to 93.74, b^* varied from 23.7 to
405 33.98, and a^* varied from -9.73 to -4.36, indicating the dried onions had more intense
406 green and yellow tones than the fresh ones. All dried samples were characterized by
407 high ΔE values, regardless of the ultrasound and blanching conditions (Table 3).

408 Although luminosity was similar for fresh, blanched-dried and US-dried onions,
409 sonicated samples had higher colour difference (ΔE) than blanched ones ($p < 0.05$).
410 The longer the sonication time (and blanching time as well), the higher was the colour
411 difference, regardless of the ultrasound amplitude. The use of ultrasound as a
412 pre-treatment to onions contributed to a significant colour change. UFD and UHD
413 (highest amplitude applied for 5 min) samples showed significantly ($p < 0.05$) higher
414 ΔE compared to other amplitudes and to BFD and BHD samples. These changes can
415 be explained by the formation of free radicals and sonochemicals as a result of
416 cavitation (Bermúdez-Aguirre, Mobbs, & Barbosa-Cánovas, 2011), which may
417 influence the food properties. The change of coordinate a^* , in specific, can be linked

418 to the formation of colour compounds (Vadivambal & Jayas, 2007) related to
419 non-enzymatic browning during treatment. The greatest colour change for the samples
420 treated by ultrasound is also ascribed to the presence of air during processing, leading
421 to enzymatic browning. In the case of blanching, the colour was better preserved as
422 the contact between samples and air was limited.

423 The colour of vegetables is determined by natural colour compounds that can be
424 oxidized during the pre-treatment, and the most important factor accelerating
425 degradation is high temperature and presence of oxygen. Enzymatic browning also
426 plays an important role in colour change due to the brown pigments formed from
427 colourless polyphenols (Maskan, 2001). Table 4 shows that the b* chroma was
428 correlated to TPC and Q 4' G at 5% significance (Table 4) in the hot-air drying, but
429 the colour coordinates had no correlation with the bioactive compounds in freeze
430 drying.

431

432 **4. Conclusions**

433

434 Blanching and ultrasound treatments significantly affected the colour, TPC, TFC,
435 individual phenolic compounds and antioxidant activity of onion slices dried either by
436 freeze drying or hot-air drying. In this work, ultrasound has been identified as an
437 alternative pre-treatment to blanching regarding the enhancement of functional
438 properties in onions. The ultrasound-treatment applied for 1-3 min at any amplitude
439 (24.4-61 μm) increased (1%-20%) the content of phytochemicals regarding phenolic

440 compounds, flavonoids and quercetin. As a consequence, sonicated onion slices (1-3
441 min) featured higher antioxidant activity than blanched ones. However, the 5
442 min-sonication had a deleterious effect (more than 10% degradation) on the bioactive
443 compounds and antioxidant activity. At last, as the leaching water from onions treated
444 with ultrasound and blanching contained high amounts of antioxidants, it may be
445 considered a valuable co-product for the food and nutraceutical industries.

446 Further research is required to optimize the retention of bioactives by varying
447 ultrasonic processing parameters such as power level, treatment time and temperature,
448 allowing a successful implementation in the food industry.

449

450 **Acknowledgements**

451

452 The authors wish to acknowledge the financial support of the Food Institutional
453 Research Measure, funded by the Irish Department of Agriculture, Fisheries and
454 Food.

455

456 **Conflicts of interest**

457

458 The authors declare that there are no conflicts of interest related to this paper.

459

460 **References**

461

- 462 Bermúdez-Aguirre, D., Mobbs, T., & Barbosa-Cánovas, G. V. (2011). Ultrasound
463 applications in food processing *Ultrasound Technologies for Food and*
464 *Bioprocessing* (pp. 65-105): Springer.
- 465 Bunea, A., Andjelkovic, M., Socaciu, C., Bobis, O., Neacsu, M., Verhé, R., & Van
466 Camp, J. (2008). Total and individual carotenoids and phenolic acids content
467 in fresh, refrigerated and processed spinach (*Spinacia oleracea* L.). *Food*
468 *Chemistry*, 108(2), 649-656.
- 469 Dewanto, V., Wu, X., & Liu, R. H. (2002). Processed sweet corn has higher
470 antioxidant activity. *Journal of Agricultural and food Chemistry*, 50(17),
471 4959-4964.
- 472 Doymaz, İ., Tugrul, N., & Pala, M. (2006). Drying characteristics of dill and parsley
473 leaves. *Journal of Food Engineering*, 77(3), 559-565.
- 474 Goupy, P., Hugues, M., Boivin, P., & Amiot, M. J. (1999). Antioxidant composition
475 and activity of barley (*Hordeum vulgare*) and malt extracts and of isolated
476 phenolic compounds. *Journal of the Science of Food and Agriculture*, 79(12),
477 1625-1634.
- 478 Hiemori, M., Koh, E., & Mitchell, A. E. (2009). Influence of cooking on anthocyanins
479 in black rice (*Oryza sativa* L. japonica var. SBR). *Journal of Agricultural and*
480 *Food Chemistry*, 57(5), 1908-1914.
- 481 Hirota, S., Shimoda, T., & Takahama, U. (1998). Tissue and spatial distribution of
482 flavonol and peroxidase in onion bulbs and stability of flavonol glucosides
483 during boiling of the scales. *Journal of Agricultural and Food Chemistry*,
484 46(9), 3497-3502.
- 485 Ioannou, I., Hafsa, I., Hamdi, S., Charbonnel, C., & Ghoul, M. (2012). Review of the
486 effects of food processing and formulation on flavonol and anthocyanin
487 behaviour. *Journal of Food Engineering*, 111(2), 208-217.
- 488 Jabbar, S., Abid, M., Wu, T., Hashim, M. M., Saeeduddin, M., Hu, B., Zeng, X.
489 (2015). Ultrasound-Assisted Extraction of Bioactive Compounds and
490 Antioxidants from Carrot Pomace: A Response Surface Approach. *Journal of*
491 *Food Processing and Preservation*, 39(6), 1878-1888.
- 492 Jacobo-Velázquez, D. A., González-Agüero, M., & Cisneros-Zevallos, L. (2015).
493 Cross-talk between signaling pathways: the link between plant secondary
494 metabolite production and wounding stress response. *Scientific Reports*, 5,
495 8608.
- 496 Kadkhodae, R., & Povey, M. J. (2008). Ultrasonic inactivation of *Bacillus* α -amylase.
497 I. Effect of gas content and emitting face of probe. *Ultrasonics Sonochemistry*,
498 15(2), 133-142.
- 499 Kalt, W. (2005). Effects of production and processing factors on major fruit and
500 vegetable antioxidants. *Journal of Food Science*, 70(1).
- 501 Keenan, D. F., Tiwari, B. K., Patras, A., Gormley, R., Butler, F., & Brunton, N. P.
502 (2012). Effect of sonication on the bioactive, quality and rheological
503 characteristics of fruit smoothies. *International Journal of Food Science &*
504 *Technology*, 47(4), 827-836.
- 505 Knorr, D., Zenker, M., Heinz, V., & Lee, D.-U. (2004). Applications and potential of

- 506 ultrasonics in food processing. *Trends in Food Science & Technology*, 15(5),
507 261-266.
- 508 Krishnaswamy, K., & Raghuramulu, N. (1998). Bioactive phytochemicals with
509 emphasis on dietary practices. *Indian Journal of Medical Research*, 108, 167.
- 510 Lin, J.-Y., & Tang, C.-Y. (2007). Determination of total phenolic and flavonoid
511 contents in selected fruits and vegetables, as well as their stimulatory effects
512 on mouse splenocyte proliferation. *Food Chemistry*, 101(1), 140-147.
- 513 Marcuzzo, E., Peressini, D., Debeaufort, F., & Sensidoni, A. (2010). Effect of
514 ultrasound treatment on properties of gluten-based film. *Innovative Food
515 Science & Emerging Technologies*, 11(3), 451-457.
- 516 Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and
517 microwave drying. *Journal of Food Engineering*, 48(2), 169-175.
- 518 Mieszczakowska-Frać, M., Dyki, B., & Konopacka, D. (2016). Effects of ultrasound
519 on polyphenol retention in apples after the application of predrying treatments
520 in liquid medium. *Food and Bioprocess Technology*, 9(3), 543-552.
- 521 Mothibe, K. J., Zhang, M., Nsor-atindana, J., & Wang, Y.-C. (2011). Use of ultrasound
522 pretreatment in drying of fruits: Drying rates, quality attributes, and shelf life
523 extension. *Drying Technology*, 29(14), 1611-1621.
- 524 Negi, P., & Roy, S. (2000). Effect of blanching and drying methods on β -carotene,
525 ascorbic acid and chlorophyll retention of leafy vegetables. *LWT-Food Science
526 and Technology*, 33(4), 295-298.
- 527 Nowacka, M., & Wedzik, M. (2016). Effect of ultrasound treatment on microstructure,
528 colour and carotenoid content in fresh and dried carrot tissue. *Applied
529 Acoustics*, 103, 163-171.
- 530 Opalić, M., Domitran, Z., Komes, D., Belščak, A., Horžić, D., & Karlović, D. (2009).
531 The effect of ultrasound pre-treatment and air-drying on the quality of dried
532 apples. *Czech Journal of Food Sciences*, 27(4), 297-300.
- 533 Pétrier, C., Combet, E., & Mason, T. (2007). Oxygen-induced concurrent ultrasonic
534 degradation of volatile and non-volatile aromatic compounds. *Ultrasonics
535 Sonochemistry*, 14(2), 117-121.
- 536 Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. *Journal of
537 Food Engineering*, 49(4), 311-319.
- 538 Rawson, A., Koidis, A., Rai, D. K., Tuohy, M., & Brunton, N. (2010). Influence of
539 sous vide and water immersion processing on polyacetylene content and
540 instrumental color of parsnip (*Pastinaca sativa*) disks. *Journal of Agricultural
541 and Food Chemistry*, 58(13), 7740-7747.
- 542 Rawson, A., Tiwari, B., Tuohy, M., O'Donnell, C., & Brunton, N. (2011). Effect of
543 ultrasound and blanching pretreatments on polyacetylene and carotenoid
544 content of hot air and freeze dried carrot discs. *Ultrasonics Sonochemistry*,
545 18(5), 1172-1179.
- 546 Rodrigues, A., Pérez-Gregorio, M., García-Falcón, M., & Simal-Gándara, J. (2009).
547 Effect of curing and cooking on flavonols and anthocyanins in traditional
548 varieties of onion bulbs. *Food Research International*, 42(9), 1331-1336.
- 549 Sarsavadia, P., Sawhney, R., Pangavhane, D., & Singh, S. (1999). Drying behaviour of

- 550 brined onion slices. *Journal of Food Engineering*, 40(3), 219-226.
- 551 Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). [14] Analysis of
552 total phenols and other oxidation substrates and antioxidants by means of
553 folin-ciocalteu reagent. *Methods in Enzymology*, 299, 152-178.
- 554 Stratil, P., Klejdus, B., & Kuban, V. (2006). Determination of total content of phenolic
555 compounds and their antioxidant activity in vegetables evaluation of
556 spectrophotometric methods. *Journal of agricultural and food chemistry*, 54(3),
557 607-616.
- 558 Tiwari, B., Patras, A., Brunton, N., Cullen, P., & O'Donnell, C. (2010). Effect of
559 ultrasound processing on anthocyanins and color of red grape juice.
560 *Ultrasonics Sonochemistry*, 17(3), 598-604.
- 561 Tsao, R., & Yang, R. (2003). Optimization of a new mobile phase to know the
562 complex and real polyphenolic composition: towards a total phenolic index
563 using high-performance liquid chromatography. *Journal of Chromatography A*,
564 1018(1), 29-40.
- 565 Turkmen, N., Sari, F., & Velioglu, Y. S. (2005). The effect of cooking methods on
566 total phenolics and antioxidant activity of selected green vegetables. *Food
567 Chemistry*, 93(4), 713-718.
- 568 Vadivambal, R., & Jayas, D. (2007). Changes in quality of microwave-treated
569 agricultural products—a review. *Biosystems Engineering*, 98(1), 1-16.
- 570 Vega-Gálvez, A., Ah-Hen, K., Chacana, M., Vergara, J., Martínez-Monzó, J.,
571 García-Segovia, P., Di Scala, K. (2012). Effect of temperature and air velocity
572 on drying kinetics, antioxidant capacity, total phenolic content, colour, texture
573 and microstructure of apple (*var. Granny Smith*) slices. *Food Chemistry*,
574 132(1), 51-59.
- 575 Xu, B., & Chang, S. K. (2008). Total phenolics, phenolic acids, isoflavones, and
576 anthocyanins and antioxidant properties of yellow and black soybeans as
577 affected by thermal processing. *Journal of Agricultural and Food Chemistry*,
578 56(16), 7165-7175.
- 579 Xu, B., & Chang, S. K. (2009). Total phenolic, phenolic acid, anthocyanin,
580 flavan-3-ol, and flavonol profiles and antioxidant properties of pinto and black
581 beans (*Phaseolus vulgaris* L.) as affected by thermal processing. *Journal of
582 Agricultural and Food Chemistry*, 57(11), 4754-4764.

583

Table 1 – Influence of ultrasound and blanching treatments followed of drying on the total phenolics content (TPC), total flavonoid content (TFC) and antioxidant activity of onion slices.

FREEZE DRYING	TPC	Retention (%)	TFC	Retention (%)	FRAP	Retention (%)	DPPH	Retention (%)
Control	9.21±0.82 ^{cdef}	---	4.10±0.08 ^{bcd}	---	11.05±0.99 ^c	---	4.42±0.82 ^{bc}	---
UFD 24.4 µm 1 min	9.65±0.24 ^{bcd}	104.87%	4.19±0.18 ^{abc}	102.08%	11.58±0.29 ^{bc}	104.87%	5.21±0.84 ^{abc}	117.98%
UFD 42.7 µm 1 min	9.48±0.40 ^{bcde}	102.99%	4.13±0.07 ^{abcd}	100.59%	11.38±0.48 ^{bc}	102.99%	5.12±0.83 ^{abc}	115.87%
UFD 61.0 µm 1 min	9.31±0.37 ^{cdef}	101.13%	4.15±0.03 ^{abcd}	101.15%	11.17±0.44 ^{bc}	101.13%	5.03±0.8 ^{abc}	113.78%
BFD 1 min	9.22±0.10 ^{cdef}	100.18%	4.16±0.10 ^{abcd}	101.27%	11.07±0.12 ^c	100.18%	4.98±0.84 ^b	112.71%
UFD 24.4 µm 3 min	11.18±1.27 ^a	121.41%	4.47±0.15 ^a	108.93%	13.41±1.52 ^a	121.41%	6.04±0.89 ^a	136.59%
UFD 42.7 µm 3 min	10.81±0.43 ^{ab}	117.48%	4.42±0.24 ^{ab}	107.65%	12.98±0.52 ^a	117.48%	5.84±0.88 ^{ab}	132.16%
UFD 61.0 µm 3 min	9.76±0.56 ^{abc}	106.06%	4.27±0.56 ^{abc}	104.06%	11.72±0.68 ^{bc}	106.06%	5.27±0.85 ^{abc}	119.32%
BFD 3 min	8.19±0.11 ^{defg}	88.96%	3.81±0.11 ^{bcde}	92.83%	9.83±0.14 ^d	88.96%	4.40±0.76 ^{bc}	100.08%
UFD 24.4 µm 5 min	8.09±0.07 ^{efg}	87.91%	3.76±0.06 ^{cdef}	91.71%	9.71±0.09 ^d	87.91%	4.37±0.75 ^{abc}	98.90%
UFD 42.7 µm 5 min	7.68±0.06 ^g	83.45%	3.49±0.10 ^{ef}	84.96%	9.22±0.07 ^{de}	83.45%	4.15±0.70 ^c	93.88%
UFD 61.0 µm 5 min	7.33±0.14 ^g	79.61%	3.15±0.06 ^f	76.75%	8.79±0.17 ^e	79.61%	3.96±0.63 ^c	89.56%
BFD 5 min	7.86±0.15 ^{fg}	85.41%	3.57±0.30 ^{def}	86.98%	9.43±0.18 ^{de}	85.41%	4.25±0.71 ^c	96.08%
HOT-AIR DRYING	TPC	Retention (%)	TFC	Retention (%)	FRAP	Retention (%)	DPPH	Retention (%)
Control	7.76±0.39 ^{abc}	---	3.34±0.36 ^{bcde}	---	9.31±0.47 ^b	---	3.82±0.67 ^{bc}	---
UHD 24.4 µm 1 min	6.50±0.37 ^{def}	83.84%	3.35±0.20 ^{bcde}	100.12%	7.80±0.45 ^{ef}	83.84%	3.36±0.70 ^{de}	87.93%
UHD 42.7µm 1 min	7.67±0.47 ^{abc}	98.88%	3.66±0.18 ^{bc}	109.43%	9.20±0.56 ^{bc}	98.88%	3.96±0.73 ^b	103.70%
UHD 61.0 µm 1 min	8.58±0.44 ^a	110.65%	4.34±0.27 ^a	130.04%	10.30±0.53 ^a	110.65%	4.43±0.87 ^a	116.05%
BHD 1 min	7.93±0.14 ^{ab}	102.24%	3.90±0.31 ^b	116.71%	9.52±0.17 ^b	102.24%	4.09±0.78 ^{ab}	107.23%
UHD 24.4 µm 3 min	6.69±0.65 ^{cde}	86.26%	3.45±0.34 ^{abcd}	103.15%	8.03±0.78 ^e	86.26%	3.45±0.69 ^{cd}	90.47%
UHD 42.7 µm 3 min	7.34±0.26 ^{bcd}	94.58%	3.79±0.35 ^{bc}	113.57%	8.80±0.31 ^{cd}	94.58%	3.79±0.76 ^{bc}	99.19%
UHD 61.0 µm 3 min	7.74±0.27 ^{abc}	99.83%	3.83±0.14 ^{ab}	114.63%	9.29±0.33 ^b	99.83%	4.00±0.79 ^b	104.70%
BHD 3 min	6.23±0.17 ^{def}	80.27%	3.10±0.33 ^{cdef}	92.67%	7.47±0.21 ^{fg}	80.27%	3.21±0.62 ^{de}	84.19%
UHD 24.4 µm 5 min	5.50±0.37 ^f	70.94%	2.70±0.17 ^f	80.85%	6.60±0.45 ^h	70.94%	2.84±0.54 ^f	74.40%
UHD 42.7 µm 5 min	6.34±0.26 ^{def}	81.69%	2.88±0.08 ^{def}	86.35%	7.60±0.3 ^{ef}	81.69%	3.27±0.58 ^{de}	85.67%
UHD 61.0 µm 5 min	7.25±0.23 ^{bcd}	93.46%	3.34±0.27 ^{bcde}	100.11%	8.70±0.27 ^d	93.46%	3.74±0.68 ^{bc}	98.02%
BHD 5 min	5.93±0.14 ^{ef}	76.46%	2.77±0.32 ^{ef}	82.84%	7.12±0.17 ^g	76.46%	3.06±0.55 ^{ef}	80.19%

For each row, values followed by the same letter are not statistically different at $p < 0.05$. Values are expressed as mean \pm standard deviation in dry weight (%) for $n=3$. TPC = Total phenolics content (mg of gallic acid equivalents per g of dry weight). TFC = Total flavonoids content (mg of quercetin equivalents per g of dry weight). FRAP and DPPH = Antioxidant activity (mg Trolox/g DW). UFD = ultrasound pre-treatment followed of freeze drying; UHD = ultrasound pre-treatment followed of hot-air drying; BFD = blanching followed of freeze drying; BHD = blanching followed of hot-air drying.

*Blanching was carried out at 70°C, Hot-air drying at 60°C and 3 m/s for 8 h, and Freeze-drying at 0.04 mbar for 72 h.

Table 2 – Effect of ultrasound and blanching treatments followed of drying on the bioactive compounds and antioxidant activity of the leaching water from onion slices.

Treatment	TPC	TFC	Q 3,4' D	Q 4' G	Q	FRAP	DPPH
UFD 24.4 μ m 1 min	0.66 \pm 0.03 ^e	0.22 \pm 0.01 ^b	10.43 \pm 0.31 ^{def}	55.56 \pm 5.42 ^{de}	4.42 \pm 0.71 ^{cd}	0.81 \pm 0.04 ^d	0.47 \pm 0.03 ^{abcd}
UFD 42.7 μ m 1 min	0.96 \pm 0.01 ^d	0.24 \pm 0.01 ^b	11.83 \pm 0.13 ^d	61.97 \pm 1.24 ^d	4.58 \pm 0.26 ^{cd}	0.79 \pm 0.06 ^d	0.46 \pm 0.11 ^{bcd}
UFD 61.0 μ m 1 min	1.31 \pm 0.07 ^c	0.26 \pm 0.00 ^b	17.67 \pm 0.04 ^d	92.31 \pm 1.31 ^c	4.71 \pm 0.47 ^c	0.78 \pm 0.05 ^d	0.45 \pm 0.12 ^{bcd}
BFD 1 min	1.52 \pm 0.02 ^a	0.71 \pm 0.29 ^a	225.05 \pm 3.00 ^a	408.37 \pm 2.50 ^a	63.0 \pm 0.92 ^a	1.1 \pm 0.05 ^a	0.60 \pm 0.08 ^a
UFD 24.4 μ m 3 min	0.43 \pm 0.02 ^g	0.06 \pm 0.01 ^c	3.67 \pm 0.15 ^{gf}	32.31 \pm 2.20 ^f	1.24 \pm 0.12 ^{cde}	0.78 \pm 0.18 ^d	0.45 \pm 0.16 ^{bcd}
UFD 42.7 μ m 3 min	0.53 \pm 0.01 ^f	0.06 \pm 0.00 ^c	3.83 \pm 0.31 ^{gf}	35.6 \pm 5.94 ^f	1.58 \pm 0.83 ^{cde}	0.93 \pm 0.06 ^{bc}	0.54 \pm 0.12 ^{ab}
UFD 61.0 μ m 3 min	0.63 \pm 0.02 ^e	0.09 \pm 0.01 ^c	7.43 \pm 0.02 ^{efg}	41.97 \pm 1.84 ^{ef}	1.67 \pm 0.14 ^{cde}	0.91 \pm 0.08 ^c	0.53 \pm 0.15 ^{abc}
BFD 3 min	1.35 \pm 0.02 ^b	0.24 \pm 0.01 ^b	208.38 \pm 3.60 ^b	325.03 \pm 12.43 ^b	38.05 \pm 3.38 ^b	0.98 \pm 0.07 ^b	0.53 \pm 0.12 ^{abc}
UFD 24.4 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
UFD 42.7 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
UFD 61.0 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
BFD 5 min	1.34 \pm 0.03 ^c	0.21 \pm 0.00 ^b	175.5 \pm 1.60 ^c	310.70 \pm 19.10 ^b	35.1 \pm 1.58 ^b	0.94 \pm 0.10 ^{bc}	0.51 \pm 0.06 ^{abc}
Treatment	TPC	TFC	Q 3,4' D	Q 4' G	Q	FRAP	DPPH
UHD 24.4 μ m 1 min	0.05 \pm 0.01 ^e	0.01 \pm 0.00 ^c	nd	7.02 \pm 1.86 ^{de}	7.5 \pm 1.05 ^{cd}	nd	nd
UHD 42.7 μ m 1 min	0.08 \pm 0.02 ^e	0.01 \pm 0.0 ^c	nd	7.82 \pm 1.31 ^d	17.0 \pm 2.1 ^b	nd	nd
UHD 61.0 μ m 1 min	1.01 \pm 0.03 ^b	0.03 \pm 0.00 ^c	nd	11.65 \pm 0.22 ^c	16.51 \pm 1.95 ^b	nd	nd
BHD 1 min	1.32 \pm 0.07 ^a	0.37 \pm 0.08 ^a	nd	306.4 \pm 23.50 ^a	31.0 \pm 2.2 ^a	0.8 \pm 0.02 ^a	0.50 \pm 0.03 ^a
UHD 24.4 μ m 3 min	nd	nd	nd	nd	nd	nd	nd
UHD 42.7 μ m 3 min	nd	nd	nd	nd	nd	nd	nd
UHD 61.0 μ m 3 min	nd	nd	nd	nd	nd	nd	nd
BHD 3 min	0.41 \pm 0.08 ^c	0.26 \pm 0.03 ^b	103.86 \pm 11.2 ^a	268.7 \pm 19.36 ^b	9.55 \pm 1.98 ^c	0.39 \pm 0.03 ^b	0.42 \pm 0.1 ^{abc}
UHD 24.4 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
UHD 42.7 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
UHD 61.0 μ m 5 min	nd	nd	nd	nd	nd	nd	nd
BHD 5 min	0.29 \pm 0.1 ^d	0.20 \pm 0.00 ^b	78.23 \pm 6.60 ^b	258.60 \pm 18.97 ^b	6.2 \pm 0.44 ^{cd}	0.34 \pm 0.10 ^b	0.39 \pm 0.08 ^{abc}

For each row, values followed by the same letter are not statistically different at $p < 0.05$. Values are expressed as mean \pm standard deviation in dry weight (%) for $n=3$. TPC = Total phenolics content (mg of gallic acid equivalents per g of dry weight). TFC = Total flavonoids content (mg of quercetin equivalents per g of dry weight). Q 3,4' D = quercetin 3,4' glucoside ($\mu\text{g/g}$); Q 4' G = quercetin 4' glucoside ($\mu\text{g/g}$); Q = quercetin ($\mu\text{g/g}$). FRAP and DPPH = Antioxidant activity (mg Trolox/g DW). UFD = ultrasound pre-treatment followed of freeze drying; UHD = ultrasound pre-treatment followed of hot-air drying; BFD = blanching followed of freeze drying; BHD = blanching followed of hot-air drying.

*Blanching was carried out at 70°C , Hot-air drying at 60°C and 3 m/s for 8 h, and Freeze-drying at 0.04 mbar for 72 h.

Table 3 – Colour of freeze dried and hot-air dried onion slices subjected to blanching and ultrasound pre-treatments.

FREEZE DRYING	L*	a*	b*	ΔE
Control	74.24±2.15 ^e	-6.23±0.53 ^a	22.79±2.80 ^c	---
UFD 24.4 μm 1 min	80.8±0.60 ^{cd}	-8.84±0.62 ^{ef}	31.07±2.17 ^a	10.88±1.13 ^g
UFD 42.7 μm 1min	81.51±1.21 ^{bcd}	-9.21±0.19 ^{fg}	29.78±1.66 ^{ab}	11.51±1.02 ^g
UFD 61.0 μm 1min	92.41±0.66 ^a	-9.01±0.43 ^{fg}	29.25±0.78 ^{ab}	19.47±0.50 ^c
BFD 1 min	86.51±0.38 ^{bc}	-7.08±0.05 ^b	25.72±0.60 ^c	12.64±0.47 ^e
UFD 24.4 μm 3 min	81.5±1.54 ^{bcd}	-8.98±0.83 ^{ef}	31.80±1.09 ^a	11.90±1.15 ^{fg}
UFD 42.7 μm 3 min	82.35±1.32 ^{bcd}	-9.32±0.21 ^{gh}	29.98±0.93 ^{ab}	12.27±0.82 ^{ef}
UFD 61.0 μm 3 min	92.41±0.30 ^a	-8.21±0.13 ^{de}	29.25±0.06 ^{ab}	19.31±0.16 ^c
BFD 3 min	89.34±0.61 ^{bc}	-7.28±0.18 ^{bc}	27.61±0.50 ^{ab}	15.97±0.43 ^d
UFD 24.4 μm 5 min	91.85±0.45 ^a	-9.30±1.04 ^{hi}	32.80±2.07 ^a	20.49±1.19 ^b
UFD 42.7 μm 5 min	91.51±1.18 ^{ab}	-9.73±0.63 ⁱ	33.97±5.83 ^a	20.87±2.55 ^b
UFD 61.0 μm 5 min	93.74±0.11 ^a	-7.97±0.45 ^{cd}	33.82±4.76 ^a	22.47±1.74 ^a
BFD 5 min	88.06±0.8 ^{ab}	-7.44±0.20 ^{bc}	29.93±0.60 ^{abc}	15.60±0.53 ^d
HOT-AIR DRYING	L*	a*	b*	ΔE
Control	74.24±2.15 ^c	-6.23±0.53 ^b	22.79±2.80 ^{de}	---
UHD 24.4μm 1 min	85.8±1.61 ^b	-7.84±0.51 ^{cd}	30.07±0.98 ^a	10.06±1.030 ^k
UHD 42.7 μm 1 min	82.501±0.36 ^b	-8.21±0.08 ^d	28.78±0.16 ^{ab}	10.74±0.20 ⁱ
UHD 61.0 μm 1 min	90.41±0.09 ^a	-6.18±0.08 ^b	28.25±0.51 ^{ab}	17.06±0.23 ^c
BHD 1 min	59.1±0.34 ^e	-6.04±0.29 ^b	23.71±0.78 ^d	15.50±0.45 ^f
UHD 24.4 μm 3 min	85.98±0.88 ^b	-7.98±0.48 ^{cd}	30.51±0.65 ^a	10.46±0.67 ^j
UHD 42.7 μm 3 min	82.85±1.02 ^b	-8.62±0.03 ^{de}	28.98±0.91 ^{ab}	10.87±0.65 ^h
UHD 61.0 μm 3 min	90.94±1.37 ^a	-6.43±0.51 ^{bc}	28.52±0.76 ^{ab}	17.66±0.88 ^b
BHD 3 min	58.29±0.46 ^e	-5.85±0.22 ^b	25.60±0.22 ^{bc}	15.70±0.33 ^e
UHD 24.4 μm 5 min	86.28±0.95 ^b	-8.40±0.28 ^d	31.05±1.86 ^a	14.76±1.03 ^g
UHD 42.7 μm 5 min	83.15±0.86 ^b	-8.82±0.38 ^{de}	29.28±1.29 ^a	15.72±0.84 ^e
UHD 61.0 μm 5 min	91.34±2.36 ^a	-6.74±0.05 ^{bcd}	28.85±1.18 ^{ab}	18.15±1.20 ^a
BHD 5 min	64.40±0.88 ^d	-4.36±0.38 ^a	29.29±1.10	15.93±0.79 ^d

For each row, values followed by the same letter are not statistically different at $p < 0.05$. Values are expressed as mean \pm standard deviation in dry weight (%) for $n=3$. UFD = ultrasound pre-treatment followed of freeze drying; UHD = ultrasound pre-treatment followed of hot-air drying; BFD = blanching followed of freeze drying; BHD = blanching followed of hot-air drying.

*Blanching was carried out at 70°C, Hot-air drying at 60°C and 3 m/s for 8 h, and Freeze-drying at 0.04 mbar for 72 h.

Table 4 – Correlation matrix of colour and chemical indices of freeze dried and hot-air dried onion slices.

FREEZE DRYING	TPC	TFC	Q 3,4' D	Q 4' G	Q	L	a	b
TPC	1.00	0.83	0.63	0.58	0.21	-0.55	-0.06	-0.23
TFC		1.00	0.52	0.66	0.34	-0.50	-0.03	-0.33
Q 3,4' D			1.00	0.19	0.09	-0.57	-0.01	-0.31
Q 4' G				1.00	0.47	-0.22	-0.20	-0.04
Q					1.00	-0.11	-0.13	-0.08
L*						1.00	-0.07	0.45*
a*							1.00	-0.54*
b*								1.00
HOT-AIR DRYING	TPC	TFC	Q 3,4' D	Q 4' G	Q	L	a	b
TPC	1.00	0.79	0.75	0.83	0.75	0.17	0.05	0.46*
TFC		1.00	0.68	0.81	0.64	0.23	-0.05	-0.27
Q 3,4' D			1.00	0.77	0.67	0.30	-0.25	-0.23
Q 4' G				1.00	0.65	0.01	-0.05	0.52*
Q					1.00	0.51	-0.17	-0.06
L*						1.00	-0.44*	0.64
a*							1.00	-0.32
b*								1.00

Chromameter describes colour in three coordinates: L, lightness, from 0 (black) to 100 (white); a, from -60 (green) to 60 (red); and b, from -60 (blue) to 60 (yellow).

TPC = Total phenolics content (mg of gallic acid equivalents per g of dry weight); TFC = Total flavonoids content (mg of quercetin equivalents per g of dry weight); Q 4' G = quercetin 4'glucoside ($\mu\text{g/g}$); Q 3,4' D = quercetin 3,4'glucoside ($\mu\text{g/g}$); Q = quercetin ($\mu\text{g/g}$).

* Represents significance at 5%.

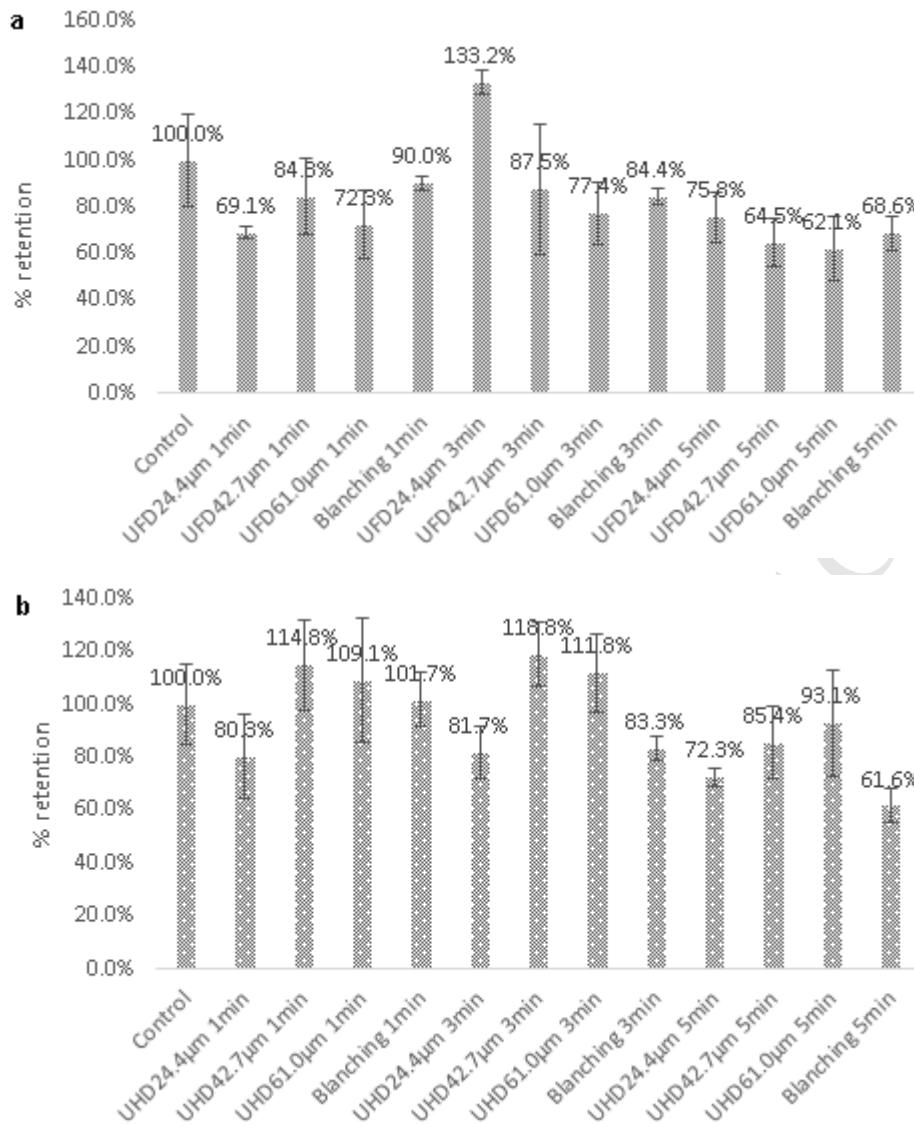


Figure 1 – Retention of quercetin 3,4'-diglucoside after different pretreatments followed of (a) freeze drying and (b) hot-air drying.

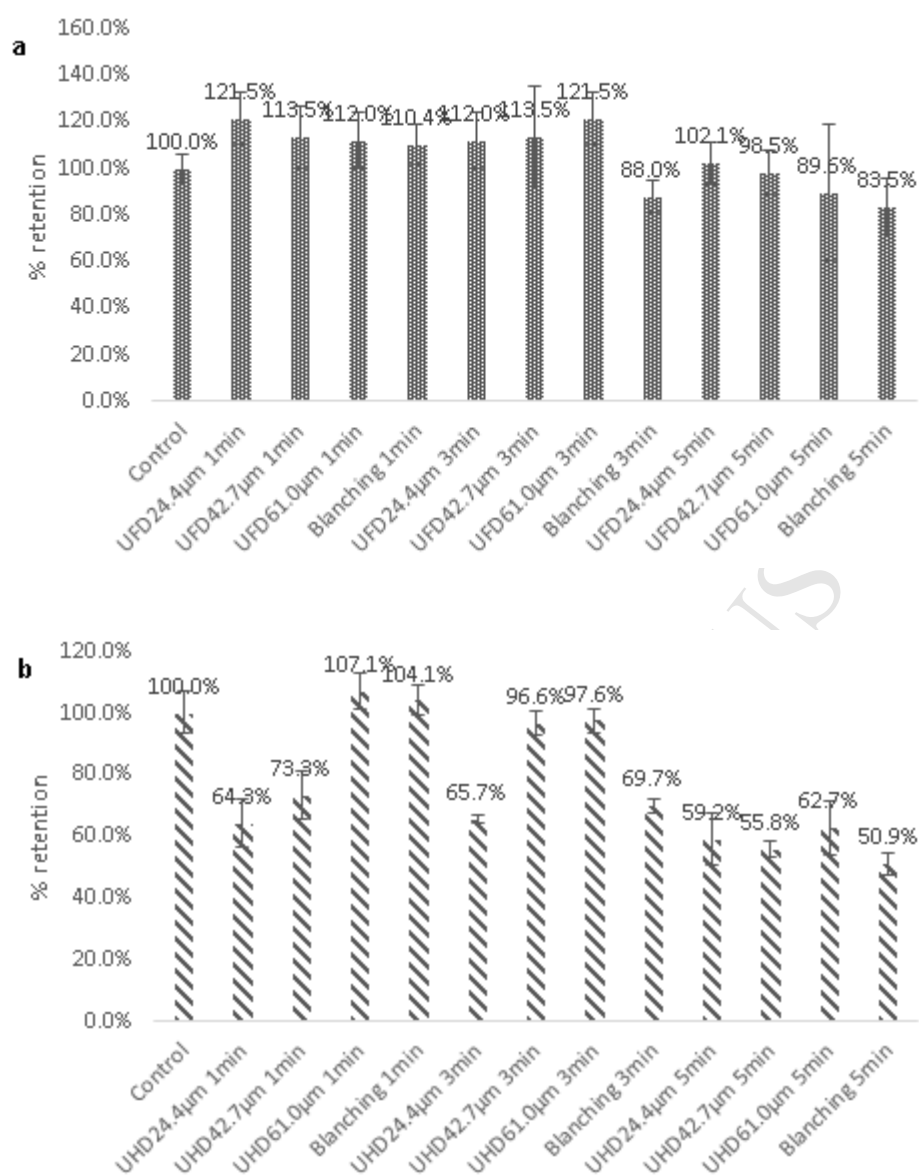


Figure 2 – Retention of quercetin 4'-glucoside after different pretreatments followed of (a) freeze drying and (b) hot-air drying.

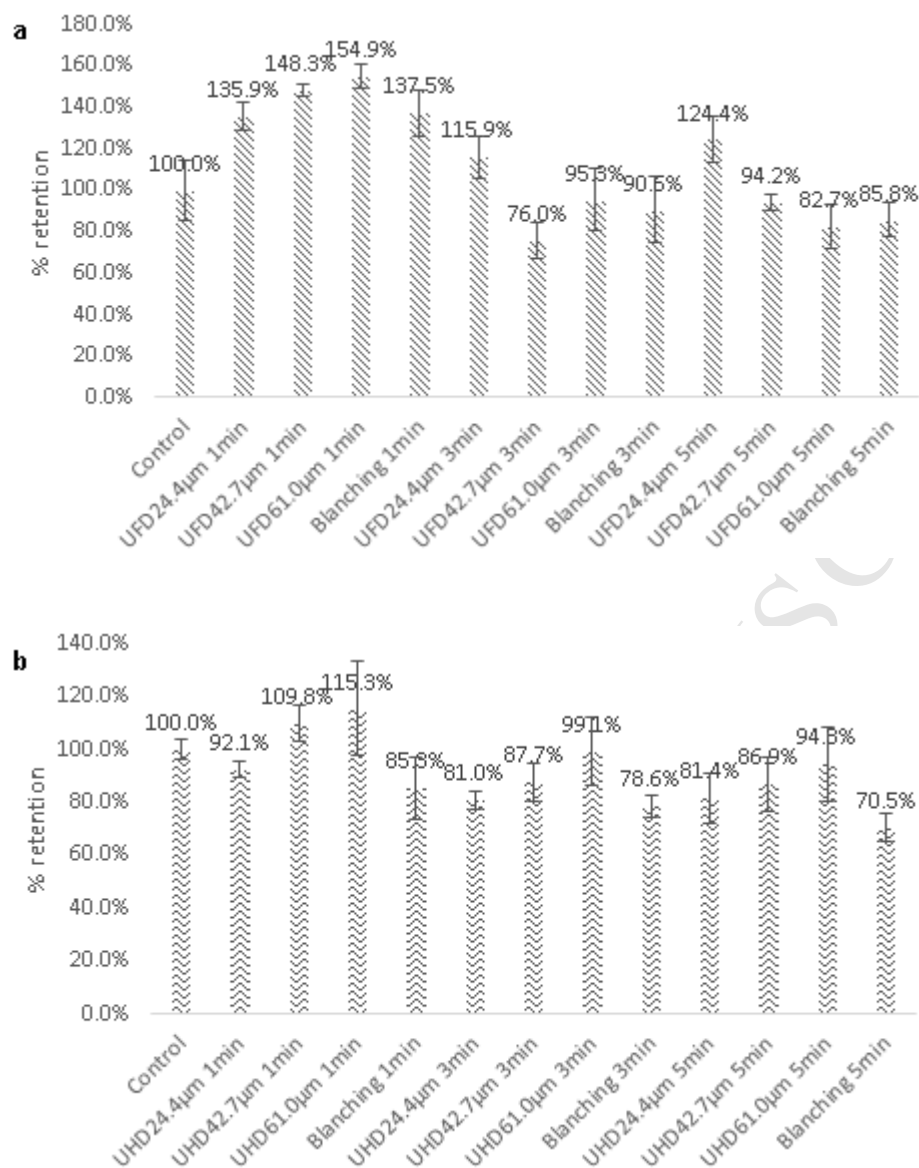


Figure 3 – Retention of quercetin after different pretreatments followed of (a) freeze drying and (b) hot-air drying.

Highlights

1. The US-treatment improved the retention of bioactive compounds in dried onions.
2. The colour change was similar between blanched and US-treated dried onions.
3. US-freeze dried onions had higher retention of phenolics than US-hot air dried.
4. Dried onions had higher antioxidant activity when sonicated for 1-3 min.