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Accelerated Drying and Rehydration of Plant Foods using Pulsed Electric Field Pre-treatment

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***Abstract* – The effect of High electric field pulses (HELP) for permeabilization of plant cells prior to hot air drying was investigated. Plant materials (grape, plum, and asparagus) were pre-treated using high electric field pulse at different pulse number and then dried in hot air oven, vacuum dryer and fluid bed dryer respectively. High electric field pulse treatment induced cell permeabilization of investigated plant material (grape, plum and asparagus). The degree of cell permeabilization (Zp) increased with increasing of pulse number. With increasing of Zp decreased the tissue hardness. Drying time for grapes, plum and asparagus was decreased drastic after HELP treatment at field strength of 1kV/cm and 100 pulses. Up to 50 % and 25% shorter drying time was achieved after HELP pre-treatment for grapes and plum receptively. The HELP pre-treated grapes showed less browning after drying compare to untreated dried sample. High electric Field pulses pre-treated grapes and plum showed distinct higher rehydration rate compare to untreated samples.**

***Key words* – High Electric Field Pulses, Drying, Rehydration Rate, Non-thermal Processing, Cell Permeabilization, Plum, Asparagus, Grape.**

I. Introduction

One of the oldest and effective methods for preservation of foods is drying. During drying water will be removed from food resulting preventing microorganism growth, decreasing weight and reducing physical and chemical changes of foods during storage [1]. Common pre-treatment of plant foods (mainly vegetable) before drying is blanching. Blanching prior drying result partially enzyme and microorganism inactivation. Furthermore, the cell membrane of plant material will be permeablized. Cell permeabilization prior drying could accelerate drying of vegetables such as potato and carrot [2, 3].

It is well known that high electric field pulse is an effective, non-thermal cell permeabilization method [4-8]. HELP as cell permeabilization method is very fast and energy saving method. HELP was used for inactivation of microorganisms [9-11], enzymes [12], permeabilization of plant cells for extraction of cell compounds [13, 14], for acceleration of fermentation process [13] as well as for accelerating osmotic drying [15, 16]. The inactivation of microorganisms is possible at field strength of $\geq$ 20 kV/cm whereas for permeabilization of plant cells distinct lower field strength (0.1-1.5 kV/cm) is necessary [4, 7, 14, 17, 18].

Hot air drying of vegetables could be accelerated using HELP as pre-treatment. Angersbach and Knorr [4] found out that the potato could be dried up to 25% faster if HELP used as pre-treatment. HELP as a non-thermal cell permeabailization method could be applied to replace the conventional blanching method that used high energy and caused environmental problem because of waste water.

The aim of this study was to investigate the effect of HELP process on permeabilization and texture softening of grapes, plum and asparagus. In addition, the effect of HELP as pre-treatment method on drying rate and rehydration rate of dried plant foods was investigate.

II. Material and Methods

Grapes (Thomson seedless), Plum and asparagus (from local market, Thailand) were used as raw materials. Grapes were used as whole fruit for Help treatment. Plum was cut in two halves and removed the seed before HELP treatment. Asparagus was cut in cylinder 1cm thickness.

A. *Equipments*

High voltage equipment was applied for cell permeabilization of raw materials. The technical Specification of equipment was as follow:

DC-High voltage generator 1-10 kV (adjustable)

Capacity of condenser 4µF

For HELP treatment the samples were inserted in HELP chamber (2 parallel electrode with area 140cm2 for each electrode cm and variable Gap between electrodes) and filled with top water (electrical conductivity of water= 0.74 mS/cm). Based on data on the frequency dependence of conductivity of intact and permeablized plant tissue, a coefficient, Zp, designated the disintegration index (Equation 1), was developed [19]:

$$Zp = 1 - b\frac{(KHF' - KNF')}{(KHF - KNF)} \text{ and } b = \frac{KHF}{KHF'} \quad (1)$$

KNF and KNF' are conductivity of untreated and treated materials in low frequency field (1 to 10 KHz); KHF and KHF' are conductivity of untreated and treated materials in high frequency field (3 to 100 MHz).

$0 \leq Zp \leq 1$ ($Zp = 0$: intact cells; $Zp = 1$: total cell permeabilization)

B. *Texture Measurement*

The texture measurement was carried out using a texture analyser (Stable Microsystem Analayser SMS, Haselmere, England). The probe size was 12 mm. During texture measurement the probe with speed of 1 mm/s compress the sample (10 to 15 mm thickness of sample) against plate up to 2 mm dept.

C. *Drying*

For drying of sample were the following dryer equipment applied: Fluidized bed dryer (ATP, Berlin, Germany). The air velocity during drying was 1.5 m/s constant. An automatic balance installed inside the dryer weight the sample every 5min during drying. The dryer was automatically turn off every 5 min, weight sample (about 5 sec.) and then turn on again for continuing the drying.

- An oven dryer (Heraeus Instrument, type 6000, Germany) was applied for hot air oven drying.
- Vacuum drying carried out in a vacuum dryer (Heraeus, 10 lit volume, Germany) at about 100 mbar and 60 °C (for grapes and plum) and 70 °C (for asparagus) respectively.

D. *Rehydration*

Determination of rehydration degree of dried sample carried out using gravimetric method. 5 g of dried sample was immersed in 100 ml boiling water for defined time (5 to 15 min). After rehydration time, the weight of rehydrated sample was measured. The rehydration degree was calculated as follow:

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$R_e = \frac{(G_r - G_p)}{G_p}$, Gr = weight of rehydrated sample, Gp = weight of dried sample.

E. *Statistical Analysis*

All the measurement were carried out at least 4 times and the average was calculated.

III. Results and Discussion

Cell permeabilization: In the table 1 is the cell permeabilization degree after HELP treatment demonstrated. Increasing the pulse number results higher Zp. Many authors have reported that the increasing of pulse number increased the Zp. Ade-Omoway et al. [20] find out that for red bell pepper, the cell membrane permeabilization using HELP increased with increasing field strength and higher pulse number. However, the increase becomes marginal after application of more than 3 pulses.

Table 1. Effect of field strength and pulse number during HELP treatment on cell permeabilization of samples.

Raw Material	**HELP Treatment**			**Zp after HELP Treatment**
	Field Strength (kV/cm)	Pulse Number	Pulse Frequency (Hz)	
Grape	1.5	100	1	0.38
Plum	1.0	100	1	0.82
Asparagus	1.02	10	1	0.11
	1.02	20	1	0.17
	1.02	50	1	0.44

Texture: HELP treatment resulted softer tissue of grapes, plum and asparagus. The tissue softening of plum after HELP treatment was higher (4%) (Figure 1) compare to plum (about 5 % softening) (Figure 2). The tissue softening of asparagus was dependent on cell permeabilization degree. Increasing Zp during HELP treatment resulted increasing the tissue softening. HELP treatment for 50 pulses (Zp=0.44) leas to about 50 % softening of asparagus as shown in figure 3.

Lebovka et al. [21] investigate the stress-deformation and relaxation tests for carrot, potato and apples tissue. They have found out that the HELP-treatment alone was not sufficiently effective to complete elimination of the textural strength of tissue. The HELP allows to attain a high disintegration of membranes and to remove of a turgor component of a texture. The combined application of the mild heat (50 °C) and HELP treatment results in additional softening effect for carrots, potatoes and apples [21].

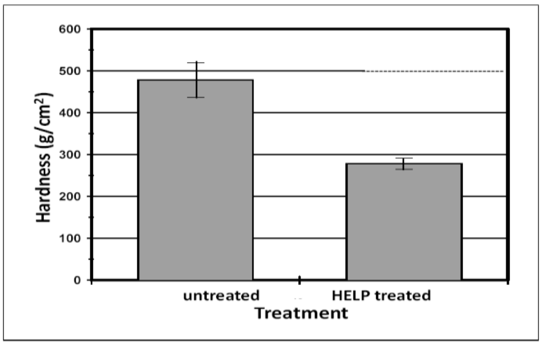

Fig. 1. Effect of HELP on hardness of grapes.

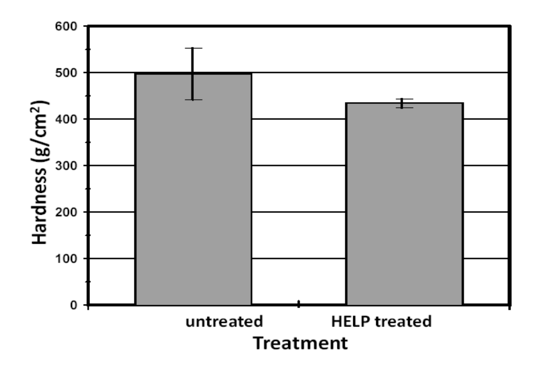

Fig. 2. Effect of HELP on hardness of plum.

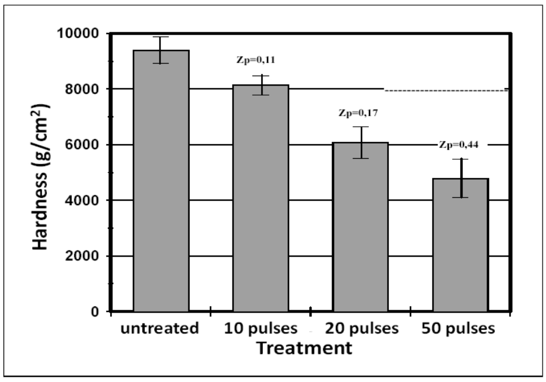

Fig. 3. Effect of HELP on hardness of asparagus.

Tedjo et al. [7] and Rastogi et al. [15] have reported the tissue softening of red beet and carrot after HELP treatment. Die Texture of plant tissue is because of cell wall composition (pectin, cellulose, hemicelluloses) as well as turgor pressure in native cells. The softening of plant materials after HELP treatment is maybe because of turgor pressure loss. During HELP treatment small pores of the semi permeable cytoplasm membrane will be occurred. This can lead to lose of turgor pressure. There is no evident that HELP can affect high molecule substances such as cellulose or hemicelluloses. We assume that the only reason for immediate tissue softening during HELP treatment is because of pore formation on cytoplasma membrane and lose of turgor pressure.

Drying: HELP treatment of grapes prior to drying led to higher drying rate (Figure 4). Compare to untreated grapes fluidized bed drying of HELP pre-treated grapes showed the highest drying rate followed by oven dryer and vacuum drying of grapes. Whereas for vacuum drying at 60 °C about 30 h was necessary, was the drying time in fluidized bed dryer 14h. Generally was the drying time for HELP pre-treated grapes 10 to 20 h shorter than untreated grapes.

The drying rate of plum was less affected by HELP treatment compare to untreated plum (Figure 5). Fluidized bed dryer was an effective drying method for drying of plum compare to vacuum drying.

Decreasing the drying time of asparagus after HELP pre-treatment was for all applied drying methods obvious. Drying of asparagus was distinct faster (3 to 4 h drying time for untreated and HELP pre-treated respectively) in fluid bed dryer compare to oven drying and vacuum drying (Figure 6).

Angersbach and Knorr [4] demonstrated the potential of HELP pre-treatment in reducing the drying time of potato cubes to approx. 1/3. In another studies Ade-Omoway et al. [22] reported faster drying on HELP pre-treated coconut and paprika compare to untreated. A reduction of drying time of approximately 25% for HELP pre-treated paprika was reported. Lebovka et al. [21] investigated the effect of HELP pre-treatment on convective drying of potato tissue. They have found that HELP treatment at moderate electric field strength (300 to 400 V/cm) could accelerate the drying rate of potato disks.

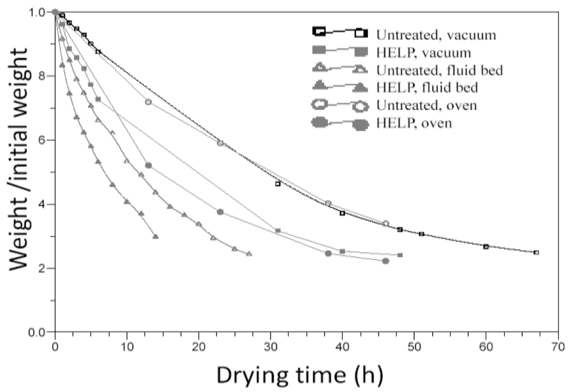

Fig. 4. Effect of HELP pre-treatment on drying rate of grapes at 60 °C.

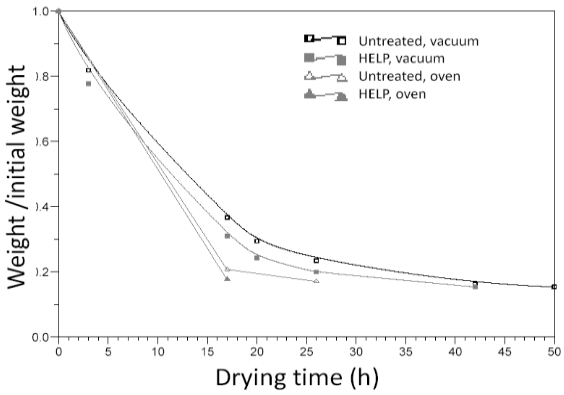

Fig. 5. Effect of HELP pre-treatment on drying rate of plum at 60 °C.

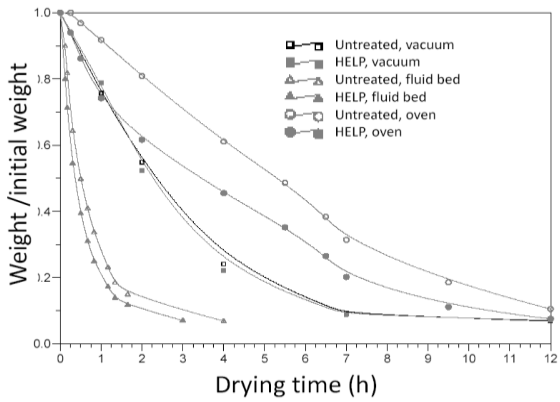

Fig. 6. Effect of HELP pre-treatment on drying rate of asparagus at 70 °C.

Rehydration: As shown in figure 7, the rehydration rate of dried HELP pre-treated grapes was higher compare to untreated dried and subsequent rehydrated grapes. The highest rehydration rate could be observed for HELP pre-treated and subsequent in vacuum dried grapes. Similar to rehydration of grapes, a distinct higher rehydration degree of HELP pre-treated and vacuum dried plum could be achieved. The rehydration degree of HELP pre-treated plum was up to 65% higher than untreated plum (Figure 8). In the case of asparagus the

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HELP pre -treatment affect negatively the rehydration rate of dried asparagus (Figure 9). Rehydration is not the opposite way of drying during drying. Texture change, migration of salt and other substances from the inside the sample on the surface could be occur during drying. This can affect the rehydration of dried samples. Heat could change the cell wall elasticity, protein coagulation and induce change in starch resulting reduce the rehydration of dried samples. During drying the phenol substances migrate from inside on the surface of sample and oxidized to polyphenol substances. Polyphenol substances could act as barrier layer and reduce the water uptake of dried sample.

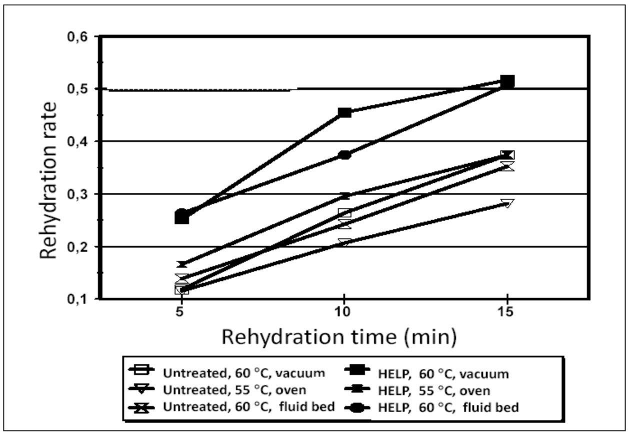

Fig. 7. Rehydration rate of grapes with or without HELP pre-treatment.

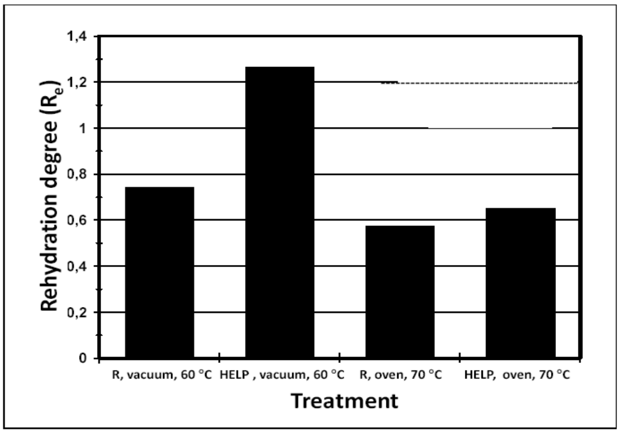

Fig. 8. Rehydration degree of untreated (R) and HELP pre-treated plum.

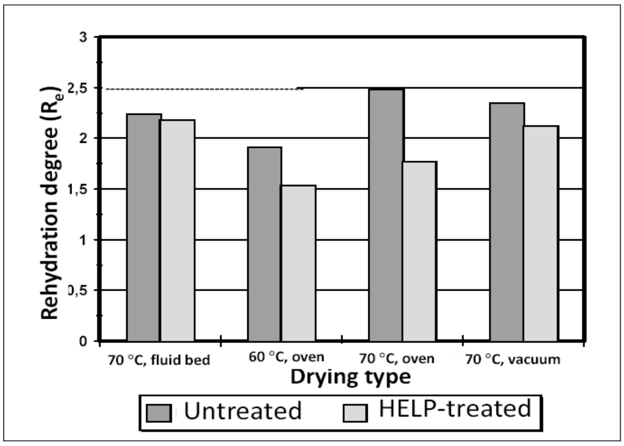

Fig. 9. Rehydration rate of asparagus with or without HELP pre-treatment.

IV. Conclusion

HELP treatment induced cell permeabilization of investigated plant material (grape, plum and asparagus). In the case of asparagus, the degree of cell permeabilization increased with increasing of pulse number. With increasing of Zp decreased the tissue hardness for all investigated samples. HELP pre-treatment accelerated drying of grapes, plum and asparagus. The drying rate was not only dependent on pre-treatment but also on drying method. Generally, fluidized bed drying resulted distinct faster drying compare to oven drying and vacuum drying. The rehydration rate of HELP pre-treated and subsequent dried grape and plum was higher than untreated sample. In contrast, HELP pre-treated asparagus showed lower rehydration rate compare to untreated sample.

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References

[1] M. Karel, Advances in food dehydration, *ZFL*, vol. 1, 1984, pp. 6 - 16.
[2] H. Mudawi, H., K.-P. Fischer-Aylof-Cook and D. List, Einfluß der Trocknungskinetik auf den Eignungswert von getrocknetem Gemüse, *ZFL*, vol. 6, 1987, pp. 482 – 488. (H. Mudawi, H., K.-P. Fischer-Aylof-Cook and D. List, Influence of drying kinetics on the suitability value of dried vegetables, ZFL, vol. 6, 1987, pp. 482-488)
[3] G. Mazza, Dehydration of carrots, Effects of pre-drying treatment in moisture transport and product quality, *J. Food Technol.*, vol. 18, 1983, pp. 113 - 123.
[4] A. Angersbach, and D. Knorr, Anwendung elektrischer Hochspannungs-impulse als Vorbehandlungsverfahren zur Beeinflussung der Trocknungscharakteristika und Rehydratationseigenschaften, *Nahrung*, vol. 41, 1997, pp. 194 – 200. (A. Angersbach, and D. Knorr, Application of High Voltage Electrical Pulses as a Pretreatment process to affect drying characteristics and rehydration properties, Food, vol. 41, 1997, pp. 194-200)
[5] H. G. L. Coster, A quantitative analysis of the voltage-current relationships of fixed charge membranes and the associated property of “punch-through”, *Biophys. J.*, vol. 5, 1965, pp. 668 - 689.
[6] E. Williams, and J. Bradley, Steady-state membrane hyper polarization by large applied currents in Nitella translucens, *Biophys. J.*, vol. 8, 1967, pp. 145 - 147.
[7] W. Tedjo, M.N. Eshtiaghi and D. Knorr, Einsatz nicht – thermischen Verfahren zur Zellpermeabilisierung von Weintrauben und Gewinnung von Inhaltsstoffen, *Flüssiges Obst*, vol. 9, 2002, pp. 578-582. (W. Tedjo, M.N. Eshtiaghi and D. Knorr, use of Non-thermal processes for cell permeabilization of grapes and extraction of ingredients, Liquid Fruit, vol. 9, 2002, pp. 578-582.)
[8] M.N. Eshtiaghi, and D. Knorr, Anwendung elektrischer Hochspannungs-impulse zum Zellaufschluß bei der Saftgewinnung am Beispiel von Weintrauben, *LVT*, vol. 445, 2000, pp. 23 - 27. (M.N. Eshtiaghi, and D. Knorr, Application of high-voltage electrical impulses for cell disruption in juice extraction using the example of grapes, LVT, vol. 445, 2000, pp. 23-27.)
[9] P.C. Wouters, and P.P.M. Smelt, Inactivation of microorganisms with pulsed electric fields: Potential for food preservation, *Food Biotechnology*, vol. 11 (3), 1997, pp. 193 - 229.
[10] H.O. Vega-Mercado, Martín-Belloso, B-L. Quin, F.J. Chang, M.M. Góngora-Nieto, G.V. Barbosa-Canovas and B.G. Swanson, Non-thermal food preservation: Pulsed electric fields, *Trends in Food Science & Technology*, vol. 8, 1997, pp. 151 - 157.
[11] B-L., F-J. Quin, Chang, F-J. G.V. Barbosa-Canovas and B.G. Swanson, Non-thermal inactivation of Saccharomyces Cerevisiae in apple juice using pulsed electric field, *Lebensm.-Wiss. u –Technol.*, vol. 28, 1995, pp. 564 - 568.
[12] S.Y., G.S. Ho, Mittal, and J.D. Cross, Effects of high field electric pulses on the activity of selected enzymes, *Journal of Food Engineering*, vol. 31, 1997, pp. 69 - 84.
[13] Tedjo, W.M.N. Eshtiaghi & D. Knorr (2002a). Impact of non-thermal pre-treatment methods on fermentation kinetics and quality criteria of fermented red paprika. Food Sci. Technol. (in Vorbereitung).
[14] M.N. Eshtiaghi, and D. Knorr, High electric field pulse pre-treatment: Potential for sugar beet processing, *Journal of Food Engineering* 52(3), 2002, pp. 265-272.
[15] N.K., Rastogi, M.N. Eshtiaghi and D. Knorr, (1999), Accelerated mass transfer during osmotic dehydration of high intensity electrical field pulse pre-treated carrots, Journal of Food Science, vol. 64 (6),1999, pp. 1020 - 1023.
[16] W. Tedjo, K. Adekunbi Taiwo, M.N. Eshtiaghi, and D. Knorr, Comparison of pretreatment methods on water and solid diffusion kinetics of osmotically dehydrated mangos, *Journal of Food Engineering* 53(2), 2002, pp. 133-142.
[17] I. Praporscic, N. Lebovka, E. Vorobiev and M. Mietton Peuchot, Pulsed electric field enhanced expression and juice quality of white grapes, *Separation and Purification Technology*, vol. 52, 2007, pp. 520-526.
[18] N. Grimi, I. Praporscic, N. Lebovka and E. Vorobiev, Selective extraction from carrot slices by pressing and washing enhanced by pulsed electric fields, *Separation and Purification Technology*, vol. 58, 2007, pp. 267-273.
[19] A. Angersbach, V. Heinz and D. Knorr, Elektrische Leitfähigkeit als Maß des Zellaufschlußgrades von zellulären Materialien durch Verarbeitungsprozesse, *LVT*, vol. 42 (4), 1997, pp. 195 - 200. (A. Angersbach, V. Heinz and D. Knorr, Electrical conductivity as a measure of the degree of cell disruption of cellular materials through processing, LVT, vol. 42 (4), 1997, pp. 195-200.)
[20] B.I.O. Ade-Omoway, N.K. Rastogi, A. Angersbach and D. Knorr, Combined effects of pulsed electric field pre-treatment and partial osmotic dehydration on air drying behavior of red bee pepper, *Journal of Food engineering*, vol. 60, 2003, pp.89-98.
[21] N.I. Lebovka, I. Praporscic, E.Vorobiev, Effect of moderate thermal and pulsed electric field treatments on textural properties of carrots, potatoes and apples, I*nnovative Food Science & Emerging Technologies* 5(1), 2004, pp. 9-16.
[22] B.I.O. Ade-Omowaye, A. Angersbach, M. N. Eshtiaghi and D. Knorr, Impact of high intensity electric field pulses on cell permeabilisation and as pre-processing step in coconut processing, Innovative Food Science & Emerging Technologies, vol. 1, 2001, p

p. 203 - 209.

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