Influence of Hot Water Treatment on Some Chemical and Mechanical Properties of Potato

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ABSTRACT

As a part for the development of a complete handling system for fresh potato, this investigation was conducted to evaluate the effect of hot water treatment on some chemical and mechanical properties of ´Victoria` potato. The results showed that there was no significant change in the density of the potatoes before and after thermal treatment; on the other hand, dry matter and moisture content differed significantly meanwhile the total soluble solids did not change. Although there was significant difference between treated and untreated potatoes in terms of all mechanical properties parameters except the Magness-Taylor (MT) reading, the discrimination efficiency calculated by statistical discriminant analysis of these parameters is low (52-66%). Analysis of impact response showed that there was no significant difference between treated and untreated potatoes for all impact parameters. The discrimination efficiency of the impact parameters was also very low (49-55%) indicating that the difference between treated and untreated potatoes was not great. The Principle Component Analysis (PCA) showed as well no linear relationship between compression and impact parameters. This could be attributed to that both divisions of potatoes (treated and untreated) nearly have similar properties and in this situation the linear correlation will be very low.

Keywords. Hot water treatment, potato, mechanical properties, impact sensor.

1. INTRODUCTION

Potato *Solanum tuberosum* is the fifth most important crop in the world since the total harvested area is about 18.9 million hectares (FAO, 2003). Sprouting (elongation of eyes) of tubers and spoilage due to invasion by bacterial and fungal pathogens are major problems of potato during storage, handling and marketing.

Basically, all fresh harvested commodities must be free of disease, insects, and chemicals, and cleaned of any dirt or dust before being packed. Accordingly, it is necessary to wash potato before grading and sorting to remove dirt and foreign materials from potato surface as well as to facilitate recognising physiological disorders and diseases. Washing efficiency varies with type of washing system, type of soil, contact time, sanitizers, and/or water temperature. Hot water treatment should sanitize the fruit, inhibit sprouting, reduce decay incidence as well as induce resistance to pathogens (Fallik, 2004), but both nutritional and sensorial (texture, color and flavor) qualities might be damaged if the thermal processing exceeds certain level (Blahovec, et al., 2000).

Ideally, the effective thermal treatment regimes must control unrequited growth, but also be non-damaging to the produce in terms of causing visible injury, notable change in colour and altering produce firmness.
The thermal treatment has been applied successfully in numerous fruits and vegetables as a non-chemical means to modify their postharvest quality (Fallik, 2004; Cantwell et al., 2003). Generally; the temperature and time of exposure to such treatment depend on the variety and size of the commodity. Sweetpotato was treated at 46ºC for 65 min (Babadoost, 1992), strawberry at 45ºC for 15 min (Wszelaki and Mitcham, 2003), onion at 55ºC for 4 min for growth inhibition (Cantwell et al., 2001), citrus at 53ºC for 2-3 min for decay control and chilling resistance depending on the cultivar and the season (Nafussi et al., 2001; Schirra et al., 1997), garlic at 55ºC for 10 min for inhibition of sprout and root growth (Cantwell et al., 2003), and potato at 57.5ºC for 20-30 min for sprout inhibition (Ranganna et al., 1998).
Understanding the effect of hot water treatment on physical, chemical and mechanical properties of potato would contribute in handling the potato more gently with consequential improving the quality. Besides, the hot water treatment improves fruit and vegetable quality, induces resistance to insect and pathogens, and maintains commodity quality during prolonged storage and marketing by extending their shelf life.
In fact, firmness is one of the most common attributes that has been used as a useful guide for growers, quality inspectors and purchasers to describe the produce quality and it has been used as a criterion for sorting agricultural products into different maturity groups or for separating overripe and damaged fruits (Chen, 1996). Due to their low speed and often destructive and subjective nature (McGlone and Kawano 1998; Felföldi and Fekete, 2004), current techniques for measuring mechanical properties are not very adaptable for on-line sorting of potatoes. In the absence of an absolute reference measure of firmness, the firmness readings of any new non-destructive method have to be compared with the Magness-Taylor "MT" reading (Peleg, 1993). Due to the lack of suitable alternatives, however, the penetrometer remains as the industry tool for firmness determination, but the lack of a strong relationship between penetrometer firmness and local variations in texture on the fruit surface limit the accuracy of firmness prediction (Delwiche and Sarig, 1991). In fact, in the last few years took place a lot of researches dealing with non destructive measuring of mechanical properties of apples, peaches, kiwi, and other horticultural produces. Although these methods have shown some success, they have not been used for grading and sorting operations due to either their unsatisfactory performance or the technical difficulty of implementing these methods for online processes, so that very few of them have gained widespread acceptance (Abbott et al., 1997).

2. OBJECTIVES

Since there are many advantages of hot water treatment of agricultural produces, its effect on chemical and mechanical properties of potato has to be investigated. Also, the impact behaviour of potatoes on the sorting lines before and after thermal treatment has to be involved. The impact sensor developed in IVIA was used to accomplish this aim. Consequently, the objectives of this study were to:-

- Determine the changes on chemical, mechanical and impact properties of potato before and after hot water treatment
- Investigate the relationship between physical and mechanical properties
- Relate the reading of impact sensor with destructive parameters.

3. MATERIALS AND METHODS

3.1. Hot Water Treatment

Potatoes ´Victoria variety` used in this study were bought directly from specialized packinghouse company and were put in an environmental chamber at constant storage conditions (10°C and 95 % RH) until the day of experiments.

One hundred tubers of potato were chosen randomly and divided into two equal divisions. Potatoes were kept in the dark at room temperature for 2 days before being tested, so that the temperature of the tuber tissues became more homogenous. Tubers were washed thoroughly to remove soil particles and then air-dried, weighed and their dimensions were measured. Hot water treatment was applied by dipping the first division (50 tubers) in hot water (57.5°C) using a 30-l thermoregulator bath for 25 min to inhibit sprouting as recommended by Ranganna et al. (1998), then directly dried with clean cloth for the further experiments. All mechanical properties were measured directly after thermal treatment.

3.2. Measurement of Physical Properties Parameters

3.2.1. Major and Minor Diameters

Both polar diameter (longitudinal or major diameter) and equatorial diameter (minor diameter) were measured for each tuber with the aid of a digital calliper. The equatorial diameter was the maximum width of the tuber in a plan perpendicular to the tuber poles, and it was measured in two different orientations and the measurements were averaged.

3.2.2. Surface Area and Perimeter

Each tuber was labelled and imaged in four different orientations with a digital camera in a black background. A commercial image analysis software was used to determine the projected surface area and perimeter of each tuber in each orientation, and then the four measurements were averaged.

3.2.3. Density

The tuber density was determined by measuring both mass and volume of each tuber. The mass was recorded using a digital balance (± 0.01g) and the volume was measured using weight-in-air and weight-in-water method using a simple designed pycnometer as described by Forbes (2000).

3.3. Measurement of Mechanical Properties

3.3.1. Compression Test Parameters

Four compression tests as described by ASAE Standards S368.4 (2001) were performed on four randomly locations on the tuber surface using Instron Universal Testing Machine (Instron 4301, Instron Corporation, USA) using 11.1 mm diameter cylindrical probe with a cross-head speed of 100 mm/min (Jindal and Techasena, 1985) for penetration depth of 10 mm. Four Force-Deformation curves were obtained for each tuber. A program by MATLAB was developed to determine the following mechanical properties parameters from each Force-Deformation data as shown in fig. 1:

- MT: Maximum force or MT firmness that occurs at rupture point (N),
- D : Deformation or displacement of the tuber from the contact until the point of rupture (mm),

- E_f : Secant modulus of Elasticity equals "MT/D" ratio (N/mm)
- E : Deformation Energy (N.mm) is the total energy required to penetrate the tuber for the whole penetration depth.
- T : Toughness (N.mm) or the mechanical energy or work required to puncture the tuber surface. It equals the area under the Force-Deformation curve until the point of rupture.

The program also calculated some additional parameters like E/MT, E/D, E/(MT.D), T/D, and T/(MT.D). The measurements were performed in one day to alleviate the effect of extended storage and the four readings of each parameter were averaged.

3.3.2. Impact Test Parameters from Impact Sensor

Before conducting the compression test, each tuber of the two divisions (the treated and untreated potatoes) was tested with impact sensor described by Moltó et al. (1996) and Burgos et al. (2002). Each tuber was dropped from 6-cm height four times on the sensor load cell in random positions. The load cell is a transducer that generates an analogical signal that is proportional to the applied impact. The signal was acquired by a personal computer through an acquisition board. The signal recorded for every drop was analysed by a computer to produce Force-Time curve, as shown in fig. 2, and a MATLAB program was written to determine the following parameters:-

- $P_1$and P_2 : Maximum force for the first and second impact resp.,
- t_1 and t_2 : Time for the first and second impact resp.,
- a_1 and a_2 : Width at half height of the first and second impact resp.,
- A_1 and A_2 : Area under first and second impact zone resp., and
- Slope : Slope until the maximum force of the first impact.

Also, the program calculated additional parameters like A_1/a_1, A_2/a_2, A_1/P_1, P_1/a_1, t_2-t_1, A_2/P_2, P_2/a_2, A_1/m, $P_1/m.a_1$, and P_1^2/m. where "m" is the mass of individual tuber.

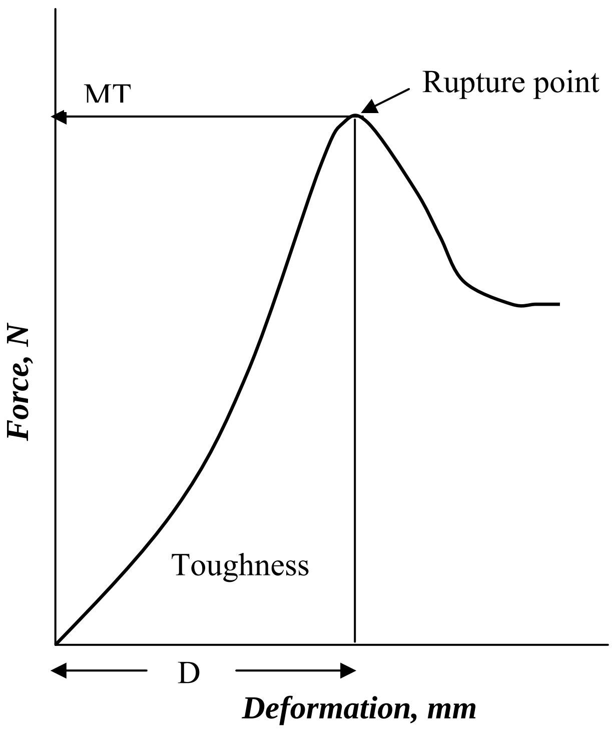

Fig. 1. Force-Deformation curve from compression test

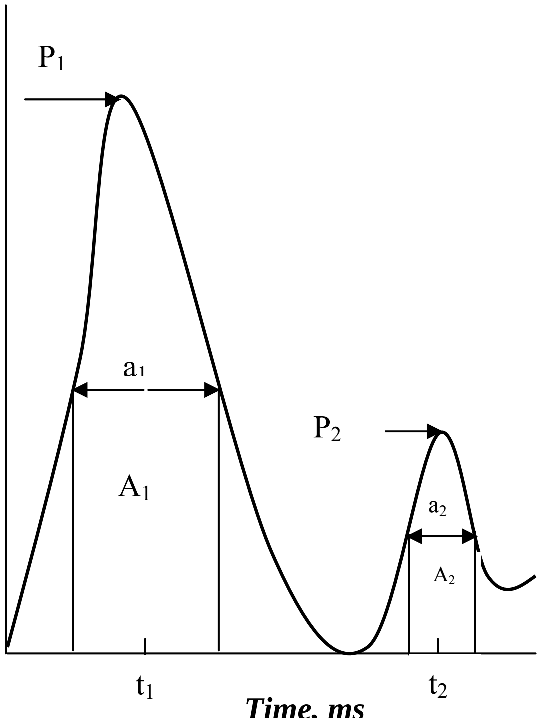

Fig. 2: Force-Time curve from impact sensor

3.4. Measurement of Chemical Properties

3.4.1. Moisture Contents (MC) and Dry Mater (DM)

After performing the impact and compression test, some portions were cut from outer and inner parts of each tuber and weighed in an aluminium cup, then dried in an oven at 70°C until constant weight was achieved. The moisture content of each tuber was calculated as a percentage of the initial wet weight. The dry matter was calculated as a percentage of final dry weight to the initial wet weight.

3.4.2. Total Soluble Solids (SS)

The remaining parts of each tuber was juiced using juicing machine and the soluble solids in each tuber were measured two times using a digital refractometer; the first measurement was made directly after juicing and the other after one hour. There was no significant difference between the two measurements. However, the two measurements were averaged and the total soluble solids were expressed in Brix degrees.

3.5. Stastical Analysis

Basically, t-test was conducted to investigate the difference between treatments. Additionally, discriminant analysis was done to estimate the discrimination efficiency of mechanical parameters to discriminate between the two divisions of potatoes. Furthermore, Principal Component Analysis (PCA) was conducted to relate impact and compression parameters using STATISTICA commercial software.

4. RESULTS AND DISCUSSION

4.1. Effect of Thermal Treatment on Chemical Properties

The influence of hot water treatment on moisture content (MC), dry matter (DM) and total soluble solids (SS) is tabulated in table 1. The moisture content was positively affected with hot water treatment. The statistical analysis showed that this difference was significant before and after the treatment. In addition, the total soluble solids was not affected by the thermal treatment, and this leads to the fact that the hot water treatment under this condition would not affect the potato quality indicated that the hot water treatment (at 57.5ºC for 25 min) did not cause cell separation, rupture or gelatinization as well as there was not any evidences of changing the tuber colour as stated by Ranganna et al. (1998).

Potato density was 1.07±0.03 g/cm^3; and its value after thermal treatment was 1.072±0.026 g/cm^3. Anyway, the statistical analysis showed that there was no significant difference in potato density before and after hot water treatment.

Table 1. Effect of thermal treatment on moisture content (MC), dry matter (DM), and total soluble solids (SS)*

Treatment	MC, %			DM, %			SS, ºBrix		
	min	max	mean±SD	min	max	mean±SD	min	max	mean±SD
Before treatment	60.72	70.40	67.22^a±1.95	29.60	39.28	32.78^a±1.95	4.55	5.40	4.92^a±0.18
After treatment	70.21	77.58	74.63^b±1.61	22.42	29.79	25.37^b±1.61	4.50	5.25	4.91^a±0.17

* Means in a column not followed by the same letter are significantly different at $p < 0.05$.

4.2. Influence of Thermal Treatment on Mechanical Properties

4.2.1. Compression Test Parameters

As shown in table 2, the statistical analysis showed that there was no significant difference between treated and untreated tubers in case of maximum force "Magness-Taylor or MT parameter" required to penetrate the tuber; meanwhile, there was significant difference between treated and untreated potatoes in terms of the rest of mechanical properties parameters. This means that either the MT firmness criteria is not a good reference to discriminate between commodity firmness because it lacks the repeatability and accuracy (Burgos et al., 2002) or it is not sensitive enough and can not stand alone to express fruit firmness. Because of fruits are complex biological products and individual variations in properties among fruits from the same sample can be large (Duprat et al., 1995), it is unlikely that one parameter will describe fruit adequately. Therefore several different tests will usually need to be conducted on any batch of fruit. It is noteworthy to show that the energy (E) required to penetrate treated potatoes is less than that required to penetrate untreated ones. Also, the same attitude was noticed for the other mechanical parameters as shown in table 2. The only exception happened in deformation "D" parameter that was 10% higher in case of treated tubers. On the contrary, discriminant analysis showed that each parameter has a certain ability to discriminate between treated and untreated potatoes. Even though there were indeed statistical differences, but they are really small for most parameters. The efficiency (Eff.) of each parameter to correctly classify potatoes is tabulated in the last column of Table 2; the criterion E/MT has the highest discrimination efficiency. However, the discrimination efficiency for all parameters is less than 70% indicating that there is a great interference between both divisions and this means that the difference between treated and untreated potatoes is not high. Moreover, there was no relationship (not presented in this article) between mechanical parameters and tuber dimensions (Major and minor diameter, area, volume and mass). Firmness and other mechanical parameters of potatoes do not depend on tuber dimensions. That means that small tuber can have lower firmness and larger ones can have higher firmness and vice versa. This attitude represents additional complexity of the difference and variation between tubers.

Table 2. Effect of thermal treatment on mechanical properties *

Treatment	Before treatment			After treatment			Eff.,
	min	max	mean±SD	min	max	mean±SD	%
MT	6.28	12.77	$9.60^{a}\pm1.37$	6.55	12.59	$9.70^{a}\pm1.01$	52
D	2.00	7.50	$4.44^{b}\pm1.12$	2.32	8.33	$4.98^{a}\pm1.14$	58
E_f	0.93	4.14	$2.28^{a}\pm0.61$	1.28	4.31	$2.06^{b}\pm0.48$	57
E	37.61	84.79	$59.95^{a}\pm7.99$	42.03	70.56	$56.20^{b}\pm5.74$	59
E/MT	4.55	8.09	$6.29^{a}\pm0.66$	4.60	7.22	$5.77^{b}\pm0.52$	66
E/D	7.22	29.99	$14.36^{a}\pm4.12$	5.98	23.25	$11.92^{b}\pm3.17$	61
E/(MT.D)	0.70	3.29	$1.52^{a}\pm0.47$	0.55	2.48	$1.23^{b}\pm0.36$	63
T/D	2.92	7.60	$5.37^{a}\pm0.73$	3.89	6.51	$5.18^{b}\pm0.52$	56
T/(MT.D)	0.42	0.74	$0.56^{a}\pm0.05$	0.44	0.69	$0.53^{b}\pm0.04$	63

*Means in a row not followed by the same letter are significantly different at $p < 0.05$

4.2.2. Impact Test Parameters from Impact Sensor

Table 3 shows the effect of thermal treatment on impact properties of the tuber. In general, it can be inferred that there was no significant difference between treated and untreated potatoes in all impact parameters as obviously indicated in Table 3. Previous works by Delwiche et al., 1989; Meredith et al., 1990; Delwiche and Sarig, 1991; Moltó et al., 1996; and Burgos et al., 2002 suggested some impact parameters such as P_1/t_1, P_1/t_1^2, P_1^2/m, m/t_2^2, slope, coefficient of restitution, and absorbed energy. It appears that the selection of one particular impact parameter over the others is largely dependent on commodity and impact method, as well as the firmness reference used by individual investigation (Abbott et al., 1999). The discrimination efficiency (Eff.) of each parameter is low (less than 70%) indicating that the difference between two divisions in terms of impact properties is not high.

Table. 3. Effect of thermal treatment on impact properties

Parameters	Before treatment				After treatment				Eff.,
	min	max	mean	SD	min	max	mean	SD	%
A_1/a_1	346.98	1239.15	771.36[a]	219.98	372.11	1324.81	766.17[a]	204.98	49
A_2/a_2	148.59	972.86	455.97[a]	170.15	138.12	1061.65	460.06[a]	167.99	51
A_1/P_1	6.39	15.59	9.45[a]	1.48	5.25	13.92	9.21[a]	1.26	55
A_2/P_2	4.61	16.85	8.57[a]	2.11	3.03	16.14	8.42[a]	2.08	51
P_1/a_1	42.87	131.21	81.34[a]	18.96	40.71	133.59	82.66[a]	17.14	55
P_2/a_2	11.04	129.99	53.89[a]	19.32	15.92	158.50	55.73[a]	19.99	54
P_1^2/m	1865	10493	4749[a]	1496	2104	10535	4901[a]	1436	54
t_2-t_1	31.7	82.35	58.59[a]	11.20	27.65	84.15	59.61[a]	10.47	53
Slope	2.75	13.84	6.88[a]	2.24	3.05	12.40	6.89[a]	2.01	52

*Means in a row not followed by the same letter are significantly different at p = 0.05

4.3.3. Relationship between Impact and Compression Parameters

This step was undertaken as a try to relate the parameters obtained from compression test (destructive measurement) and parameters obtained from impact test (non-destructive measurement) to find the suitable reference that can be used to express the mechanical properties non-destructively. The measurements obtained during impact test by the sensor can be related to a valid or a known reference of firmness in order to demonstrate the validity of the sensor for measuring this property. In addition, each parameter obtained during the compression test was tested to be used as a reference for mechanical properties measurement as a try to make a relationship between one of these references and reading from impact sensor. Principal Component Analysis (PCA) was conducted to know the dominant pattern and major trend between impact and compression parameters. By means of this statistical technique, the data of the potato properties (compression and impact properties) could be represented by the first two or three principal components instead of so many variables without much loss of information. The first three components explained 68.66% of the original variance in the data set of potato properties (PC_1: 32.98%, PC_2: 22.74% and PC_3: 12.94). The cosine of the angle between vectors in the loading-weight plot is a measure of the correlation between the tuber properties if the total explained variance of the *x*-variables is > 80% (Sharma, 1996). The first three components explained variance less than 80% as well as none of the score plots of PC_1 versus PC_2, PC_1 versus PC_2 and PC_2 versus PC_3 did separate potatoes that differ in their impact or compression properties. This result is illustrated in the loading-weight plot shown in fig. 3. For simplicity, only the first two PC's are presented because the others were much lower.

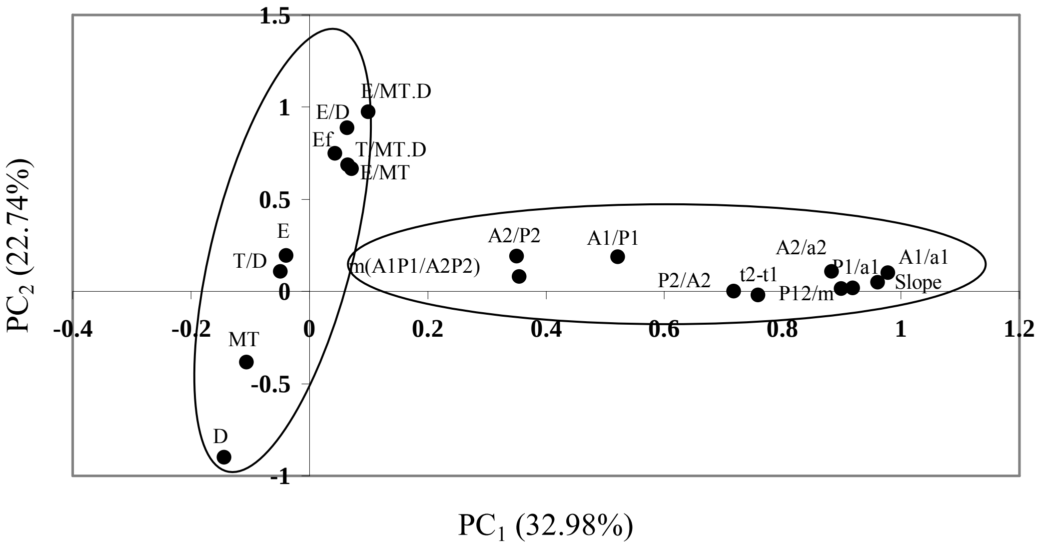

Fig.3: Loading-weight plot between first and second principal components corresponding to PCA of the data set.

It can be inferred from the graph that the compression parameters are related with each other because they are projected around the same axis; similarly, the impact parameters are related to one another as well due to their projection around the vertical axis. However, there was not a strong linear relationship between the compression and impact parameters. It seems that the two kinds of parameters are orthogonal and this is the case when the firmness difference is very narrow between groups under study. This emphasized that both divisions of potatoes have similar properties and in this situation the linear correlation would be very low, but when the firmness range in the inspected samples is sufficiently wide the correlation between impact and compression criteria would be quite good (Peleg, 1993). Obviously, if one group is softer than the other, the relationship would be enhanced and this point has to be considered to examine wide ranges of firmness. The same attitude was obtained by Ian et al. (2004) who reported that in the case of fruit with similar firmness the correlations diminish and it is difficult to ensure an adequate separation of the fruit. Also, Desmet et al. (2004) stated that no discrimination could be made for cultivar that has the same susceptibility to compression. She attributed this result to that the fruit properties between susceptible and less susceptible cultivars differed in almost all the fruit properties measured, but cultivar with same susceptibility differed in only a few fruit properties.

5. CONCLUSION

This study was conducted to investigate the effect of hot water treatment on some chemical and mechanical properties of potato. Also, relationship between compression and impact parameters was studied.

Based on experiments, there was no significant change in the density of the potatoes before and after thermal treatment; on the other hand, moisture content and dry matter differed significantly meanwhile the total soluble solids did not change. There was significant difference between treated and untreated potatoes in terms of all compression parameters except in case of Magness-Taylor (MT) reading, but the discrimination efficiency of these parameters is low (52-66%). In addition, all mechanical parameters and tuber dimensions (diameter, area, volume or mass) are independent.

On the other hand, analysis of impact response showed that there was no significant difference between treated and untreated potatoes in all impact parameters. The discrimination efficiency of the impact parameters was also very low (49-55%) indicating that the difference between treated and untreated potatoes is not great. Moreover, there was no relationship between compression and impact parameters because the difference between firmness for all examined tubers was not high indicating that the hot water treatment did not alter potato properties.

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