Study of the Relationships Between Tuber Nitrate and Some Qualitative Traits of Potato Tuber (cv. Agria) by Statistical Analysis

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Tuber nitrate is one of the major factors affecting the quality of potato. The present study was conducted to determine the relationships between tuber nitrate and some tuber characteristics (weight, specific gravity, tuber diameter, dry matter percentage of peel, total and peeled tuber, and amount of nitrate in peel, cortex and pith) in Agria potato tuber by using the statistical analyses of correlations, stepwise regression and path analysis. Peel, cortex and pith nitrate had significantly positive correlations with total tuber nitrate. While, tuber weight, specific gravity, tuber diameters, total and peeled tuber dry matter percentage had negative correlation with the total tuber nitrate. The specific gravity and pith nitrate had the most significant negative and positive correlation with total tuber nitrate, respectively. The results of stepwise regression showed that the pith nitrate, specific gravity and peel nitrate were the important characteristics of tuber nitrate. Path analysis showed that the pith nitrate and specific gravity had highest positive and negative direct effects on the total nitrate. So, in this experiment tuber specific gravity and, pith and peel nitrate had significant effect on the total nitrate and hence tuber quality.

Key words: Tuber nitrate; dry matter percentage; specific gravity; stepwise regression; path analysis; correlation coefficients.

Potato (Solanum tuberosum L.) is one of the major crops in the world and has a specific place in the human nutritional pyramid1. It is consumed in different forms, depending on the variety of potato (such as cooked, french-fried, chipped, etc.)2. Agria is one of the most important varieties. It is used in both the fresh market and the processing industry3.

Tuber quality is a critical issue and must be improved, but, the parameters of defining the best-quality potatoes are not clearly defined. These parameters can by consider as the degree of excellence or acceptability by the consumers. So, this definition can be changed by consumers’ needs or the industrial process, where the potato is required1,4,5. Usually, the quality of potato depends on its physical and chemical properties6-7.

Although, tuber weight and size are the most important characteristics of consumer’s interest, while other factors such as, specific gravity and tuber dry matter have significant influence on the quality of potatoes used in the food processing industry8-11.

Tuber dry matter is an effective factor for the texture of cooked and fresh tubers. Many researchers have observed that minimum amount
of tuber dry matter for tuber processing must be higher than 20%. Generally, the concentration of tuber dry matter has a positive effect on tuber storage. Dry matter percentage is different among tubers of growing on the same plant and throughout different parts of tuber as well. The amount of dry matter is usually highest in the cortex area and lowest in the pith area. There exists a positive relationship between the dry matter and specific gravity of tuber. Many researchers have demonstrated that the specific gravity can be a suitable measure for estimating tuber dry matter4, 8, 12-15.

The amount of nutrients present in tuber is a critical parameter for improving the quality of potato. Tubers include both valuable nutrients and poisonous substances. The nutritional quality of potato tubers can be controlled by establishing a balance between these nutritious and harmful compounds16,17. Tuber nitrate concentration is a major concern for potato quality and its excessive amounts can be dangerous for human health. Although, nitrate itself is considered to be of low toxicity, its metabolites (such as nitrite, nitric oxide) and reaction products with secondary amines and amides are hazardous for human health and can lead to serious diseases such as cancer, Alzheimer’s disease, abortion and etc.18-20. Potato tuber is classified among the crops with low nitrate concentration, but, if not controlled, it can be harmful when taken in large amounts. The concentration of nitrate in potato tubers oscillates among 40 -740 ppm of fresh matter, but the average of that must be less than 300 ppm of fresh matter21, 22. Total amount of nitrates depends on different factors, such as the soil, weather conditions, potato cultivar, amount of the fertilizer used (especially, nitrogen fertilizer), tuber size and maturity and etc.18, 21. On the other hand, the amount of nitrates is usually highest in the peel and cortex area and lowest in the pith area12.

Although tuber characteristics can be affected by production systems and environmental factors during the growth season, a change in one of these parameters increases or decreases the other one4, 5, 23. For example, some researchers have mentioned a positive correlation between dry matter concentration and specific gravity, negative correlation between tuber nitrate content and specific gravity, negative relationship between tuber nitrate and dry matter and, the effect of increased amounts of tuber dry matter and tuber weight on the increase in tuber size. SO, the evaluation of correct relationship between these parameters can be important for understand tuber quality12, 24-27. Simple correlation is one of the methods of studying the relationship between the above-stated parameters. As, simple correlation is a simple technique, the path analysis is required to explain the precise relationship. Path coefficient analysis separates direct effects from the indirect effects of the causal components on the dependent component28.

A number of studies have been carried out using the simple correlation and path coefficient, but most of these investigations were focused on tuber yield, while relatively less attention has been paid to the factors affecting the quality of potato used in the processing industry28. So, the purpose of present investigation was to determine the interrelationships among tuber nitrate and other quality-affecting parameters of market potatoes (Agria variety) by using simple correlation, stepwise regression and path analysis.

MATERIALS AND METHODS

Plant Materials

According to Kirkman et al. (2007), different size ranges of potato are acceptable in different regions of the world for potato chips processing. For example, 40-95 mm in most of the European countries and 45-105 mm in USA29. Also, according to the instruction of the Manual of Fruit and Vegetable Organization of Tehran Municipality, the best tuber size for market tuber is 60-100 mm30. So, in this study, 50 kg Agria potatoes were bought from the vegetable market (Mohammadshahr, Karaj, Alborz, Iran) and tuber of 40-100 mm were isolated for further experiments. Then, 20 tubers were randomly selected, washed and weighted. Specific gravity and tuber diameters (small and large) were determined and in order to study tuber nitrate and dry matter percentage, each tuber was divided to four equal parts. One part was used for measuring the percentage of dry matter in tuber-peels and the peeled tubers. The second part was used for determining the amount of nitrate in tuber peels, cortex and pith. While, other two parts were used for measuring the total
Fresh weight and tuber diameters
The fresh weight and diameters (small and large) of potato tubers were measured by Digital Scales and vernier caliper respectively.

Tuber specific gravity
Specific gravity of potato tubers was determined by using the following formula:
Specific gravity = weight in air / (weight in air - weight in water)

Dry matter percentage
For calculating dry matter percentage of tuber peel, peeled tuber and whole tuber, fresh weights of the samples were recorded, separately. Then, the samples were dried in hot-air oven at 75 °C till they acquired constant weight and the dry matter percentage was calculated.

Estimation of nitrate concentration
For estimating nitrate concentration of peel, cortex, pith and whole tuber, each sample was milled and nitrate concentration (NO₃⁻ ions) of soap was measured by Nitrate meter (Compact NO₃⁻ Meter; B-343, twin NO₃⁻, HORIBA, Ltd JAPAN).

Statistical analyses
Correlation coefficients and stepwise multiple regression analysis were performed using SAS program (SAS Institute, Cary, N.C.; Version 9, 1). The relative importance of direct and indirect effects of characters (remaining stepwise multivariate regression method), on the total tuber nitrate, was performed using Path program (Path-Coefficients analysis software, Mashhad College of Agriculture, written by Garcia De Moral edit by M.H. Mahdizadeh).

RESULTS AND DISCUSSION

Correlation coefficients
Correlation coefficients, computed between different pairs of characters, are presented in Table 1. Results have shown that the concentration of peel, cortex and pith nitrites had positive correlations with total tuber nitrate concentration. In this experiment, the maximum positive coloration between total tuber nitrate and parameters was obtained by pith nitrate (r = 0.78). So, total tuber nitrate concentration was affected by nitrate concentration of tuber parts and pith nitrate had the maximum effect on it. Although, usually maximum amounts of nitrate present in the potato tuber are seen in peel, and the cortex area contains more nitrate than the pith area. But in most of tuber varieties, the pith contains more area ratio than the other parts. So, the pith area can exert different effects on the total nitrate than cortex and peel.

Specific gravity had negatively significant correlation with total tuber nitrate concentration (r = -0.71). In the same way, total tuber nitrate concentration had negative correlations with dry matter percentage (peeled and whole tuber). Also, the correlation between specific gravity and total tuber dry matter percentage was positive and significant (r = 0.78; Table 1). These results are in agreement with other researchers.

Tuber weight and diameters (large and small) had negatively significant correlation with total tuber nitrate (-0.59, -0.53 and -0.68, respectively). The small tubers usually are immature and the amount of nitrate concentration in such tubers is high. Furthermore, the peel area has high nitrate concentration and the ratio of peel in small tuber is higher than that of the large tuber. So, the amounts

Stepwise regression
Results of stepwise analysis show that only three variables were related to total tuber nitrate concentration (Table 2). These variables are: pith nitrate concentration (62%), specific gravity (24%), and peel nitrate concentration (3%). According to the results, 89% of variation in total tuber nitrate concentration could be attributed to these three aforementioned variables. The other variables were not included in the stepwise analysis due to their low relative contributions. The predicted equation for determining the total
Table 1. Calculation of correlation coefficient among the experimental potato traits.

<table>
<thead>
<tr>
<th></th>
<th>Tuber weight</th>
<th>Specific gravity</th>
<th>Large tuber diameter</th>
<th>Small tuber diameter</th>
<th>Total tuber weight</th>
<th>Peel tuber nitrate</th>
<th>Cortex tuber nitrate</th>
<th>Pith tuber nitrate</th>
<th>Total tuber dry matter percentage</th>
<th>Peel dry matter percentage</th>
<th>Peeled tuber dry matter percentage</th>
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<td>Tuber weight</td>
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<td>Specific gravity</td>
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<td>Large tuber diameter</td>
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<td>&lt;.0001**</td>
<td>0.0197**</td>
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<tr>
<td>Small tuber diameter</td>
<td>0.95</td>
<td>0.67</td>
<td>0.95</td>
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<td>Total tuber nitrate</td>
<td>-0.59</td>
<td>-0.71</td>
<td>-0.53</td>
<td>-0.68</td>
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<td>Peel nitrate</td>
<td>-0.28</td>
<td>-0.15</td>
<td>-0.26</td>
<td>-0.32</td>
<td>0.6</td>
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<td></td>
<td>0.2376**</td>
<td>0.524**</td>
<td>0.2695**</td>
<td>0.1738**</td>
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<td>Cortex nitrate</td>
<td>-0.54</td>
<td>-0.6</td>
<td>-0.49</td>
<td>-0.59</td>
<td>0.58</td>
<td></td>
<td></td>
<td>0.39</td>
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<td></td>
<td>0.0141**</td>
<td>0.0052**</td>
<td>0.0286*</td>
<td>0.0061**</td>
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<td>0.0924**</td>
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<td>Pith nitrate</td>
<td>-0.46</td>
<td>-0.31</td>
<td>-0.38</td>
<td>-0.5</td>
<td>0.78</td>
<td>0.66</td>
<td>0.43</td>
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<td>0.0438*</td>
<td>0.19**</td>
<td>0.1031**</td>
<td>0.0256*</td>
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<td>0.0017**</td>
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<td>Total dry matter percentage</td>
<td>0.27</td>
<td>0.78</td>
<td>0.16</td>
<td>0.32</td>
<td>-0.53</td>
<td>-0.2</td>
<td>-0.41</td>
<td>-0.22</td>
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<td>Peel dry matter percentage</td>
<td>0.2572*</td>
<td>&lt;.0001**</td>
<td>0.5123**</td>
<td>0.1665**</td>
<td>0.0165**</td>
<td>0.3915**</td>
<td>0.0753**</td>
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<tr>
<td>Peeled tuber dry matter percentage</td>
<td>0.03</td>
<td>0.66</td>
<td>-0.01</td>
<td>0.11</td>
<td>-0.4</td>
<td>-0.17</td>
<td>-0.21</td>
<td>-0.02</td>
<td>0.64</td>
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<td>0.8952**</td>
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<td>0.9622**</td>
<td>0.6423**</td>
<td>0.0816**</td>
<td>0.4771**</td>
<td>0.3843**</td>
<td>0.9417</td>
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<td>0.0646**</td>
<td>0.0015**</td>
<td>0.1435**</td>
<td>0.0416*</td>
<td>0.0108**</td>
<td>0.1787**</td>
<td>0.0848**</td>
<td>0.144**</td>
<td>&lt;.0001**</td>
<td>0.1147**</td>
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</tbody>
</table>

**P<0.01; *P<0.05; ns = Non-significant
tuber nitrate is as follows:

\[ Y = 4506.385 + 0.42575 X_1 - 4011.22 X_2 + 0.05959 X_3 \]

Where \( X_1 \) is pith nitrate concentration, \( X_2 \) is specific gravity and \( X_3 \) is the peel nitrate concentration.

**Path analysis**

In this experiment, total tuber nitrate was considered as a dependent component and in order to get clear images of the effects of causal components (remaining stepwise multivariate regression method) on the dependent component, the correlation coefficients were partitioned into direct and indirect effects by path analysis (Table 3). Results of path analysis have shown that the specific gravity had highest negative direct effect (-0.531) on the total tuber nitrate concentration. Also, the lowest indirect effects on the total tuber nitrate concentration were observed with specific gravity (-0.181). Moreover, tuber pith and peel nitrate contributed positively towards total tuber nitrate through each other. In this experiment, peel nitrate had least significant positive and direct effect (0.202) on the total tuber nitrate concentration. Whereas, highest indirect effects on total tuber nitrate concentration was observed by peel nitrate (0.397; Table 3).

According to these results, increase of specific gravity with direct effect on total tuber nitrate and indirect effects on pith and peel nitrate can led to a decline in total tuber nitrate. On the other hand, increase of pith and peel nitrate can lead to decreased specific gravity and subsequently increase the total tuber nitrate. Other researchers have observed a negative relationship between nitrogen-containing compounds and specific gravity\(^{25, 32}\). These relations can be understand by tuber starch concentration and relationship of that whit tuber nitrogen compounds and specific gravity which mentioned above\(^12\). Also, results about peel nitrate are in agreement whit other researchers which have observed a positive effect of peeling on decreasing tuber nitrates for processing or cooking\(^{22}\).

**CONCLUSIONS**

It can be concluded from the present study that, pith nitrates are more effective on the total tuber nitrate than the cortex and peel nitrate. On the other hand, the effect of peel nitrates on the total tuber nitrates is stronger than the cortex nitrates. Also, specific gravity had highest direct effect on the total tuber nitrates. So, the specific gravity of tuber, pith nitrate and peel nitrate had major contributions to the total tuber nitrates. Hence, breeding of these traits can possibly lead to decreased amount of total tuber nitrate and improve tuber quality. According to the results of this experiment, in preparing potato tubers for processing or cooking or French-fries, peeling can decrease tuber nitrate level. Moreover, use tubers potatoes with high specific gravity can lead to low nitrate concentration and high dry matter contact and subsequently increase the quality of potato.

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