BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, September 2016. Vol. **13**(3), 1749-1755

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

Amir Ali Najm[1], Farzad Paknejad[1]*, Ali Kashani[1], Mohammad Reza Ardakani[1] and Mohammad Reza Haj Seyed Hadi[2]

[1]Department of Agronomy, Faculty of Agriculture and Natural Resource, Karaj Branch, Islamic Azad University, Karaj, Iran.
[2]Department of Agronomy, Faculty of Agriculture, Roudehen Branch, Islamic Azad University, Roudehen, Iran.

http://dx.doi.org/10.13005/bbra/2326

(Received: 11 May 2016; accepted: 16 July 2016)

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 mater 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 pyramid[1]. 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 industry[3].

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 required[1, 4, 5].Usually, the quality of potato depends on its physical and chemical properties[6, 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 industry[8-11].

Tuber dry matter is an effective factor for the texture of cooked and fresh tubers. Many researchers have observed that minimum amount

* To whom all correspondence should be addressed.
E-mail: farzadpaknejad@gmail.com

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 matter[4, 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 compounds[16,17]. 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 matter[21, 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 area[12].

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 one[4, 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 quality[12, 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 component[28].

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 industry[28]. 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 USA[29]. 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 mm[30]. 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 tuber nitrate and total tuber dry matter percentage.

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[13]

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[31].

Estimation of nitrate concentration

For estimating nitrate concentration of peel, cortex, pith and whole tuber, each sample was milled and nitrate concentration (No_3^- ions) of soap was measured by Nitrate meter (Compact No_3^- Meter; B-343, twin No_3^-, 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 nitrates 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[12, 18].

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[12, 24-26, 32, 33]. Such relations can occur due to the presence of tuber starch, which can be related to tuber nitrate content, specific gravity and tuber dry matter percentage. The starch is one of the main compounds of tuber dry matter with high specific gravity (1.65 g/cm^3), and the usual concentration of starch in tuber potatoes oscillates among 63-83.6% of dry matter. So, an increase in the amount of starch can lead to increase in tuber dry matter percentage and specific gravity[12]. On the other hand, an increase in the amount of starch can lead to a decrease in tuber nitrate concentration[12]. These results are in agreement with the studies of other researchers[12, 24-26, 32, 33].

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.

	Tuber Weight	Specific gravity	Large tuber diameter	small tuber diameter	Total tuber nitrate	Peel nitrate	Cortex nitrate	Pith nitrate	Total tuber dry matter percentage	Peel dry matter percentage	Peeled tuber dry matter percentage
Tuber weight	1										
Specific gravity	0.61	1									
	0.0042**										
Large tuber diameter	0.97	0.52	1								
	<.0001**	0.0197**									
small tuber diameter	0.95	0.67	0.95	1							
	<.0001**	0.0013**	<.0001**								
Total tuber nitrate	-0.59	-0.71	-0.53	-0.68	1						
	0.0063**	0.0004**	0.0162**	0.001**							
Peel nitrate	-0.28	-0.15	-0.26	-0.32	0.6	1					
	0.2376^{ns}	0.524^{ns}	0.2695^{ns}	0.1738^{ns}	0.005**						
Cortex nitrate	-0.54	-0.6	-0.49	-0.59	0.58	0.39	1				
	0.0141**	0.0052**	0.0286*	0.0061**		0.0077**	0.0924^{ns}				
Pith nitrate	-0.46	-0.31	-0.38	-0.5	0.78	0.66	0.43	1			
	0.0438*	0.19^{ns}	0.1031^{ns}	0.0256*	<.0001**	0.0017**	0.0614^{ns}				
Total dry matter percentage	0.27	0.78	0.16	0.32	-0.53	-0.2	-0.41	-0.22	1		
	0.2572^{ns}	<.0001**	0.5123^{ns}	0.1665^{ns}	0.0165**	0.3915^{ns}	0.0753^{ns}	0.3418^{ns}			
Peel dry matter percentage	0.03	0.66	-0.01	0.11	-0.4	-0.17	-0.21	-0.02	0.64	1	
	0.8952^{ns}	0.0015**	0.9622^{ns}	0.6423^{ns}	0.0816^{ns}	0.4771^{ns}	0.3843^{ns}	0.9417^{ns}	0.0024**		
Peeled tuber dry matter percentage	0.42	0.66	0.34	0.46	-0.56	-0.31	-0.39	-0.34	0.91	0.36	1
	0.0646^{ns}	0.0015**	0.1435^{ns}	0.0416*	0.0108**	0.1787^{ns}	0.0848^{ns}	0.144^{ns}	<0001**	0.1147^{ns}	

**P<0.01; *P<0.05; ns = Non-significant

tuber nitrate is as follows:

$$Y = 4506.385 + 0.42575\ X1 - 4011.22\ X2 + 0.05959\ X3$$

Where X1 is pith nitrate concentration, X2 is specific gravity and X3 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).

Table 2. Stepwise regression of tuber nitrate (dependent variable) and other traits (independent)

Added trait to model	Stepwise regression stages		
	1	2	3
Intercept	135.490	4415.119	4506.385
Pith nitrate	0.68151	0.54246	0.42575
Specific gravity		-3930.21	-4011.22
Peel nitrate			0.05959
R^2	0.62	0.86	0.89

Table 3. Path analysis of total tuber nitrates

	Pith nitrate	Specific gravity	Peel nitrate
Pith nitrate	0.482	0.164	0.133
Specific gravity	-0.15	-0.531	-0.031
Peel nitrate	0.318	0.079	0.202
	Residual effect=0.355		

Underlined amounts show direct effects.

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.

ACKNOWLEDGMENTS

The authors are gratefully acknowledge the Islamic Azad University (Roudehen and Karaj Branch), and Young Researchers Club of the Islamic Azad University, for their support to the part of present project.

REFERENCES

1. Golmohammdi, A. and A.H. Afkari-Sayyah, *Long-Term Storage Effects on the Physical Properties of the Potato.* International Journal of Food Properties, 2013. **16**(1): p. 104-113.
2. Ellstrand, N.C., *Dangerous liaisons?: when cultivated plants mate with their wild relatives*2003, U.S.A: The Johns Hopklins University Press.
3. Keiser, A., M. Häberli, and P. Stamp, *Quality deficiencies on potato (< i> Solanum tuberosum</i> L.) tubers caused by< i> Rhizoctonia solani</i>, wireworms (< i> Agriotes</i> ssp.) and slugs (< i> Deroceras reticulatum</i>,< i> Arion hortensis</i>) in different farming systems.* Field Crops Research, 2012. **128**: p. 147-155.
4. Raj, D., *Technological innovations in potato processing*2012, India. Delhi: Narendra publishing house.
5. Seefeldt, H.F., E. Tønning, and A.K. Thybo, *Exploratory sensory profiling of three culinary preparations of potatoes (Solanum tuberosum L.)*. Journal of the Science of Food and Agriculture, 2011. **91**(1): p. 104-112.
6. Booysen, L., A.T. Viljoen, and H.C. Schönfeldt, *A comparison of the eating quality of selected potato cultivars from two potato production regions in South Africa.* Journal of the Science of Food and Agriculture 2012. **doi:10.1002/jsfa.5813**.
7. Rytel, E., et al., *Changes in glycoalkaloid and nitrate contents in potatoes during French fries processing.* Journal of the Science of Food and Agriculture, 2005. **85**(5): p. 879-882.
8. Mosa, A.A., *Effect of the Application of Humic Substances on Yield, Quality, and Nutrient Content of Potato Tubers in Egypt*, in *Sustainable Potato Production: Global Case Studies*, Z. He, R. Larkin, and W. Honeycutt, Editors. 2012, Springer Science+Business Media B.V.: Netherlands. Dordrecht. p. 471-492.
9. Marshall, B., H. Holwerda, and P. Struik, *Synchronisation of tuber growth in potato (< i> Solanum tuberosum</i>): a statistical model.* Field Crops Research, 1993. **32**(3): p. 343-357.
10. Ziadi, N., et al., *Efficiency of controlled-release urea for a potato production system in Quebec, Canada.* Agronomy Journal, 2011. **103**(1): p. 60-66.
11. Burke, J., T. O'donavan, and P. Barry, *Effect of seed source, presprouting and desiccation date on the processing quality of potato tubers for French fry production.* Potato research, 2005. **48**(1): p. 69-84.
12. Lisiñska, G. and W. Leszczyñski, *Potato science and technology*1989, Essex, England: Elsevier Applied Science.
13. Liu, Q., et al., *Advanced analytical techniques to evaluate the quality of potato and potato starch*, in *Advances in Potato Chemistry and Technology*, J. Singh and L. Kaur, Editors. 2009, Elsevier Inc: USA. New York. p. 221-248.
14. Alvarez, M.D., W. Canet, and C. Fernandez, *Effect of modified starch concentration and freezing and thawing rates on properties of mashed potatoes (cv. Kennebec).* Journal of the Science of Food and Agriculture, 2007. **87**(6): p. 1108-1122.
15. Thybo, A.K., et al., *Prediction of sensory texture quality attributes of cooked potatoes by NMR-imaging (MRI) of raw potatoes in combination with different image analysis methods.* Journal of food engineering, 2004. **61**(1): p. 91-100.
16. Lachman, J., et al., *Effect of peeling and three cooking methods on the content of selected phytochemicals in potato tubers with various colour of flesh.* Food Chemistry, 2013. **138** p. 1189–1197.
17. Najm, A.A., et al., *Effect of Integrated Management of Nitrogen Fertilizer and Cattle Manure on the Leaf Chlorophyll, Yield, and Tuber Glycoalkaloids of Agria Potato.* Communications in Soil Science and Plant Analysis, 2012. **43**(6): p. 912-923.
18. Mondy, N.I. and R. Ponnawpalam, *Effect of Magnesium Fertilizers on Total Glycoalkaloids and Nitrate N in Katahdin Tubers.* Journal of Food Science, 1985. **50**(2): p. 535-536.
19. Anjana, S. Umar, and M. Iqbal, *Factors responsible for nitrate accumulation: A review*, in *Sustainable Agriculture*, E. Lichtfouse, et al., Editors. 2009, Springer Science+Business Media B.V.: Netherlands, Dordrecht. p. 533-549.
20. Speijers, G., et al., *Evaluation of agronomic practices for mitigation of natural toxins*2010, Brussels, Belgium: ILSI Europe a.i.s.b.l.
21. Ierna, A., *Influence of harvest date on nitrate contents of three potato varieties for off-season production.* Journal of Food Composition and Analysis, 2009. **22**(6): p. 551-555.
22. Pêksa, A., et al., *Changes of glycoalkaloids and nitrate contents in potatoes during chip processing.* Food Chemistry, 2006. **97**(1): p. 151-156.
23. Najm, A.A., et al., *Effects of conventional, integrated and organic production systems on leaf chlorophyll, growth characteristics and tuber yield of agria potato*, in *9th Solanaceae Conference*2012: Neuchatel, Switzerland. p.

209.

24. Schippers, P., *The relationship between specific gravity and percentage dry matter in potato tubers*. American journal of potato research, 1976. **53**(4): p. 111-122.
25. Belanger, G., et al., *Nitrogen fertilization and irrigation affects tuber characteristics of two potato cultivars*. American journal of potato research, 2002. **79**(4): p. 269-279.
26. Giletto, C., H. Echeverría, and V. Sadras, *Fertilización nitrogenada de cultivares de papa (Solanum tuberosum) en el sudeste bonaerense*. Ciencia del suelo, 2003. **21**(2): p. 44-51.
27. Van der Zaag, D., *Potatoes and Their Cultivations in The Netherlands*1992: Netherlands Potato Consultative Institute and The Ministry of Agriculture and Fisheries.
28. Asghari-Zakaria, R., M. Fathi, and D. Hasan-Panah, *Sequential path analysis of yield components in potato*. Potato research, 2007. **49**(4): p. 273-279.
29. Kirkman, M.A., *Global Markets for Processed Potato Products*, in *Potato biology and biotechnology: advances and perspectives*, D. Vreugdenhil, et al., Editors. 2007, Elsevier: oxfoard, UK. p. 27-44.
30. Anonymous, *instruction for the grading and pricing of potato tubers*2012, Tehran, IRAN: Fruits and Vegetables Organization of Tehran Municipality (Department of hygiene and Quality Control). 1-10.
31. Kumar, P., et al., *Effect of nitrogen rate on growth, yield, economics and crisps quality of Indian potato processing cultivars*. Potato Research, 2007. **50**(2): p. 143-155.
32. Verma, S., T. Sharma, and K. Joshi, *Relation between specific gravity, starch and nitrogen content of potato tubers*. Potato research, 1975. **18**(1): p. 120-122.
33. Torres, M.D.A. and W.C. Parreno, *Thermal Processing and Quality Optimization*, in *Advances in Potato Chemistry and Technology*, J. Singh and L. Kaur, Editors. 2009, Elsevier Inc: USA. New York. p. 163-219.
34. Sinden, S., L. Sanford, and R. Webb, *Genetic and environmental control of potato glycoalkaloids*. American journal of potato research, 1984. **61**(3): p. 141-156.