Effect of Temperature and Water Potential on Sprout Vigor of Potato (*Solanum tuberosum* L.) Seed Tuber

Ifayanti Ridwan (Corresponding author)
Department of Agronomy, Faculty of Agriculture, Hasanuddin University, Makassar 90245, South Sulawesi, Indonesia. Tel: +62-411587064. E-mail: *ifayanti@yahoo.com.au*

Phil H. Brown
School of Medical and Applied Science, Central Queensland University, Bundaberg DC, QLD 4670, Australia Tel: +61 3 8676 7028 E-mail: *p.h.brown@cqu.edu.au*

Shaun N. Lisson
School of Agricultural Science, University of Tasmania, Hobart TAS 7005, Australia, Tel: +62 3 6226 2999. E-mail: *shaun.lisson@csiro.au*

Cri Wahyuni
Department of Agronomy, Faculty of Agriculture, Hasanuddin University, Makassar 90245, South Sulawesi, Indonesia. Tel: +62-411587064. E-mail: *cri_wahyuni@yahoo.com*

(Received: Aug 10, 2014; Reviewed: Oct 27, 2014; Accepted: Nov 17, 2014)

Abstract: A study was conducted to examine sprouting on potato seed tuber over a range of different temperature and moisture conditions. The Experiment was conducted under controlled environment conditions using a Terratec thermo-gradient table at the School of Agricultural Science, University of Tasmania. The trial involved exposing seed tubers cv. Russet Burbank (grade 40-60 g) sourced from one seed lot to three water potentials (-0.6 MPa, -0.02 MPa and -0.01 MPa) at each of four different temperatures (10, 15, 20 and 25 °C). The growth medium used in the trial was vermiculite (Grade 2, Australian vermiculite and Perlite Co-P/L). The water potential treatments were prepared based on the relationship of water content and water potential by Whalley *et al.* (2001). Four seed tubers were planted in each container filled with growth medium at a 10 cm depth and covered by the growth medium before the containers were resealed. Using a pseudo replication design with temperature as the block, the moisture treatments were randomized within each temperature treatment with two replicate containers for each treatment combination. The design therefore provided a total of 8 tubers for each temperature and water potential combination, and a total of 24 treatment combinations overall. An analysis of variance and least significant difference (LSD) procedure using SPSS for windows version 14.0 was performed to determine the response of the tuber seeds to temperature and moisture. Temperature and moisture significantly affected sprout growth rate, assessed as the sprouting capacity of the tubers (FW sprouts per FW tubers). Sprouting capacity of seed tubers increased with increasing temperature and water potential. There was a significant interaction between temperature and moisture treatments on the sprouting capacity ($p<0.05$). The differences between water potential treatments were greater at higher temperature, with differences between sprouting capacity of tubers exposed to dry and wet conditions particularly evident at temperatures of 20 and 25 ºC. Relation between the result and risk in plant response to warmer climate as an impact of global warming is discussed.

Keywords: Temperature; soil water potential; potato; sprouting; vigor

1. Introduction

Tuber quality, and in particular the percentage of tubers with quality characteristics that make them marketable, is an important yield component in the potato industry. Tuber quality is especially important in potato crops designated for processing as key tuber quality attributes, such as size and shape, affect processing factory efficiency and profitability. It is widely accepted that a strong relationship exists between stem number and tuber size distribution (Haverkort *et al.*, 1990; Struik *et al.*, 1990; Iritani *et al.*, 1983), making the stem number become one of one of the key factors affecting tuber size distribution hence tuber quality. Stem number has been known to be determined by sprouting pattern of the seed tuber which performance is affected by seed physiological age (Struik and Wiersema, 1999; Knowles *et al.*, 2003; Grice, 1988; Knowles and Botar, 1991; Roy and Jaiswal, 1997; Reust, 1994 cited in Struik and Wiersema, 1999; Knowles and Knowles, 2006). Many seed tuber management practices are aimed at controlling tuber physiological age at planting to deliver a desired stem number.

While physiological age of seed tubers has been demonstrated to have a major effect on plant stem number and therefore on tuber number per plant and tuber size distribution (Struik and Wiersema, 1999; Knowles and Knowles, 2006), the effect of planting environment on seed performance is not well understood, and the effects of planting conditions on stem number have not been examined. There is evidence in published field trial results supporting the hypothesis that stem number may be influenced by planting environment. For example, for seed of similar age the number of stems per plant was found to be lower when planting in autumn (2.2 stems per plant) than in spring (3.3 stems per plant) in Tunisian growing conditions (Fahem and Haverkort, 1988). This difference may have been associated with differences in temperature, with average temperatures of 27.5 ºC and 10 ºC during autumn and spring respectively. According to Reust *et al.* (2001), growing conditions and soil temperature can affect the expression of vigor of old seed in the field, with low soil temperature at planting delaying emergence and decreasing the vigor of the old seed. This conclusion was also supported by Beukema and van der Zaag (1979) who proposed that a physiologically old seed tuber is susceptible to low temperature. Despite this, no data or reports of the effect of soil temperature at planting on the stem number of seed tubers from different ages have been published.

As well as temperature, moisture at planting is rarely taken into account as a factor that affects the stem number or physiological aging of the seed tuber. Soil moisture conditions at planting have been examined in many studies, but are usually associated with disease development rather than plant growth and development. Generally, recommendations state that seed tubers require sufficient moisture to support sprouts until emergence and that excess water in this stage should be avoided as it may lead to poor soil aeration which could increase disease incidence (eg. Pavlista, 2003). Soil moisture can also affect the time to emergence by affecting the maximum sprout growth rate. Sprout growth rate decreases with decreasing soil water potential and this effect is greater at high temperature than at low temperature (Firman *et al.*, 1992). While effects of water deficit on crop establishment and yield components in potato have been extensively studied (eg. Jeffries and MacKerron, 1987; Stalham and Allen, 2004; Karafyllidis *et al.*, 1996; Mackerron *et al.*, 1988), little is known on the effect of this factor on sprouting. Several studies have documented reduction in stem number following drought treatment (Heuer and Nadler, 1995; Jeffries and MacKerron, 1987; MacKerron and Jeffries, 1986), but in these studies water stress treatments were imposed after plants have emerged and therefore the responses were not related to moisture conditions during planting. A decrease in stem number from 5.0 to 4.7 stems per plant was observed when soil water potential was decreased from -7 kPa to -70 kPa at the 50% emergence stage (MacKerron and Jeffries, 1986).

According to King and Stark (1997) excessive soil water at planting also affects the soil temperature, which can result in a decrease in sprout growth and delayed emergence from physiologically older tubers. Previous studies incorporating temperature and moisture treatments at planting have focused on crop establishment attributes such as sprout growth and time to emergence (Firman *et al.*, 1992). No studies have specifically investigated the possible interaction of planting environment and seed tuber physiological age on sprout number or stem number. The research documented in this section investigates the interaction between temperature and moisture content at planting on the sprouting of the seed tubers. The study tested the hypothesis that temperature and soil water potential at planting affect the sprouting characteristics of the seed tuber.

2. Materials and Methods

2.1 Plant Material

Seed tubers of the cultivar Russet Burbank, size grade 40-60 g, were used in the trial. After a curing period of 10 days at room temperature following harvest, the seed tubers were kept in a 4 ºC cold store for 395 days until the start of experiment. To avoid disease, tubers were dipped in fungicide (Rovral at 1 g L^{-1}) and dried before planting.

2.2 Growth Media and Water Potential

The growth medium used in the trials was vermiculite (Grade 2, Australian vermiculite and Perlite Co-P/L). In this experiment, three water potential treatments were utilized. A field capacity treatment (-0.01 MPa) was set up by saturating vermiculite and leaving it over night to drain based on the method developed by Whalley *et al.* (2001). The remaining water potential treatments were established using the relationship between water potential and water content developed by Whalley *et al.* (2001).

The relationship between soil water content and water potential was initially calibrated using a psychrometer (SC 10 thermocouple psychrometer Decagon Device, Pullman, Washington) and the following calibration for water potential,Y, was obtained:

$$Y = 0.0971\, q^{-1.1223} \qquad (1)$$

where q is the gravimetric water content.

Based on the calibration, the moisture treatments in all experiments were established by equilibrating 0.19 g and 3.36 g water g^{-1} dry vermiculite for the -0.6 MPa and -0.02 MPa moisture content treatments, respectively. After a 24 hours equilibration period, the vermiculite for each water potential preparation was placed in plastic containers and sealed with a lid to prevent water loss from the container in order to maintain constant water potential throughout the trial.

2.3 *Experimental design and statistical analysis*

The experiment was conducted and involved exposing seed tubers sourced from one seed lot to three water potentials (-0.6 MPa, -0.02 MPa and -0.01 MPa) at each of five different temperatures (10, 15, 20 and 25 °C). The experiment was carried out using a Terratec thermo-gradient table at the School of Agricultural Science, University of Tasmania. The temperature treatments were set up on the thermo-gradient table by setting the temperature to 0 °C at one end of the table and 25 °C at the other end of the table. The thermo-gradient table was set up a week before the experiment was started in order to reach equilibrium. Temperature treatments were established by measuring the temperature at different positions on the table and setting up partitions using polystyrene material around sections of the table where the desired temperatures existed.

Containers filled with vermiculite at the target water potentials were placed at each of the partitioned zones on the thermo-gradient table. Four seed tubers were planted in each container at a 10 cm depth and covered by the growth medium. Containers were then sealed to prevent water loss. Using a pseudo replication design with temperature as the block, the moisture treatments were randomized within each temperature treatment with two replicate containers for each water potential treatment at each temperature. The design therefore provided a total of 8 tubers for each temperature and water potential combination, and a total of 24 treatment combinations overall.

After 19 days, sprout and tuber weights were recorded. Sprouting capacity was calculated as gram fresh weight (FW) sprouts per gram FW tuber. An analysis of variance and least significant difference (LSD) procedure using SPSS for windows version 14.0 was performed to determine the response of the tuber seeds to temperature and moisture.

3. Results

3.1 *Effect of temperature and moisture on sprouting capacity*

Temperature and moisture significantly affected sprout growth rate, assessed as the sprouting capacity of the tubers (FW sprouts per FW tubers). Sprouting capacity of seed tubers increased with increasing temperature and water potential (Table 1). The increase in sprouting capacity with increasing temperature was statistically significant, with a fivefold increase between the 10 ºC and 25 ºC treatments. An approximate doubling in sprouting capacity between the highest and lowest water potential treatments was noted, with significantly higher sprouting capacity in the higher water potential treatments (-0.01 MPa and –0.02 MPa) compared to the lowest water potential treatment (-0.6 MPa).

Table 1. Sprouting capacity of seed tubers at different temperatures and water potentials. Tubers were exposed to temperature and water potential treatments in sealed containers filled with vermiculite for 19 days before assessment. Data are means of 8 replicate tubers.

Treatments	Sprouting capacity (g FW sprouts g^{-1} FW tuber)
Temperature (ºC)	
10	0.010 a
15	0.028 b
20	0.044 c
25	0.056 d
Moisture (MPa)	
-0.6	0.024 a
-0.02	0.039 b
-0.01	0.041 b

Values followed by same letter for each treatment are not significantly different (p=0.05) l.s.d .= 0.004.

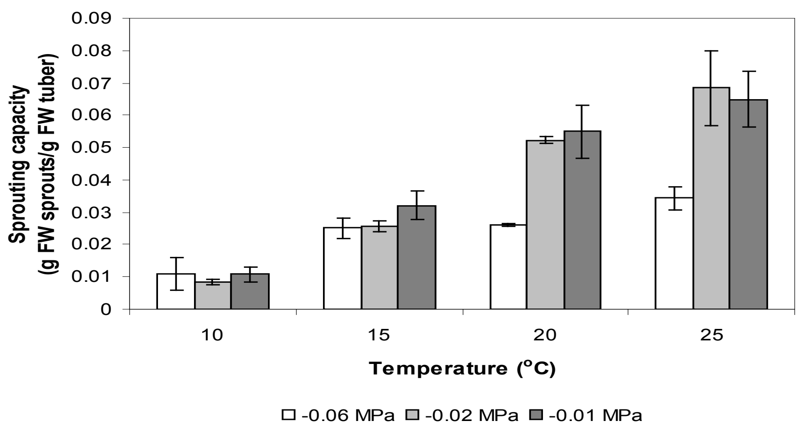

Figure 1. Interaction between temperature and water potential on sprouting capacity. Tubers were exposed to temperature and water potential treatments in sealed containers filled with vermiculite for 19 days before assessment. Data are means of 8 replicate tubers. Error bar corresponds to standard error of the mean.

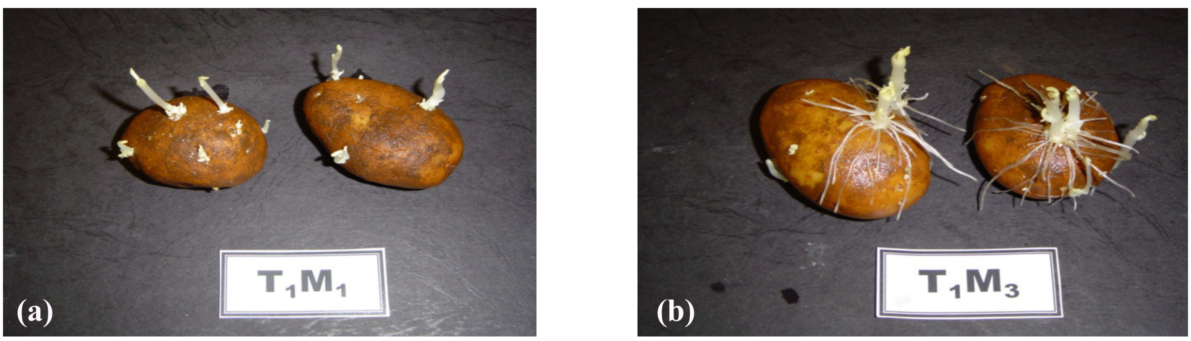

Figure 2. Sprout growth at 10 ºC (a) - 0.6 MPa (b) - 0.02 MPa.

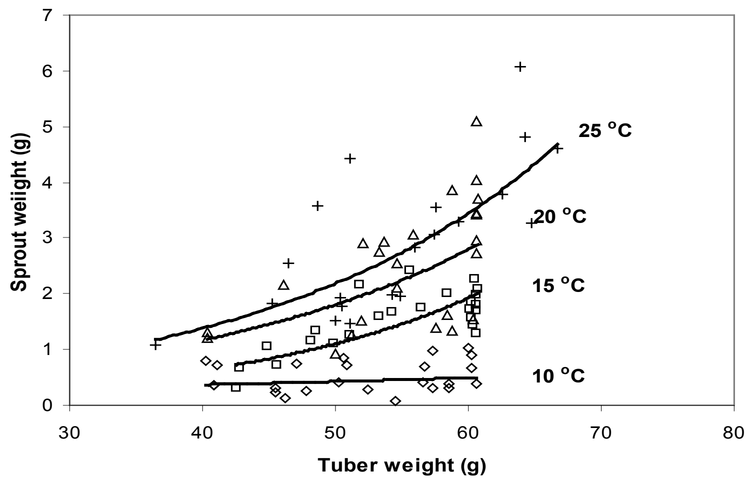

Figure 3. Relationship between sprout weight and tuber weight for tubers exposed to different temperatures of 10 ºC (¯), 15 ºC (£), 20 ºC (r) and 25 ºC (+) for 19 days in sealed container. Data comprises of all of the water potential treatments.

3.2 Interaction between temperature and moisture on sprouting capacity

There was a significant interaction between temperature and moisture treatments on the sprouting capacity ($p<0.05$). The differences between water potential treatments were greater at higher temperature, with differences between sprouting capacity of tubers exposed to dry and wet conditions particularly evident at temperatures of 20 and 25 ºC (Figure 1).

It was also noted that higher water potential promoted more root development (not measured) at the base of sprouts (Figure 2). Sprout length was less variable between water potential treatments, but ranged from approximately 0.5 - 2 cm at 10 ºC to 5 - 7 cm at 25 ºC.

Lots of variability in sprout length was observed on individual tubers. Sprout weight was associated with the weight of individual tuber (Figure 3). There was tendency that sprouts weight increased with tuber weight. This trend is less obvious at lower temperature but is evident at higher temperature (20 - 25 ºC).

4. Discussion

While both temperature and water potential have been shown previously to influence sprouting (Struik, 2007; Firman *et al.*, 1992), this experiment demonstrated the interaction between the two factors, with differences induced by varying water potential only occurring at temperatures above 15 ºC. Temperatures of 20-25 ºC have previously been reported to be optimal for sprouting (Klemke and Moll, 1990), and the findings of this experiment indicate that when temperature is optimum for sprout growth prevailing moisture conditions can affect the vigour of the sprouts.

Lack of available water will influence the water uptake by the seed tuber (Svensson, 1977) which is needed for physiological processes in the plant and as a medium for biochemical reactions (Taiz and Zeiger, 2002) such as the transportation of soluble sugar into the growing bud. The rate of these reactions is higher at higher temperatures, so the effect of reduced water uptake associated with low media water potential would be expected to be greater at higher temperatures.

Cell expansion mechanisms may also be affected by the availability of the moisture, resulting in larger sprouts at higher water potential. This might explain the advantage of pre-planting irrigation in supporting uniform germination in crop agronomy practices (Pandey, 2007). In addition, soil moisture also is proposed to be important for root formation (Beukema and van der Zaag, 1979), a conclusion that was supported by the observations of root development in the different water potential in the experiment. The presence of larger roots at the base of the sprouts would be expected to increase water uptake by tubers, contributing to the differences in sprout size and vigor between water potential treatments noted at higher temperatures. Though not considered in this study, the other potential confounding factor is the changes in carbon dioxide concentration in the sealed container and the associated effect on plant growth, especially water use and radiation use efficiency.

Result of this study implies to the strategy to maintain normal sprout growth when micro climate is prevailing such as increase in soil temperature above the optimum level or decrease in water content altered either by higher air temperature or extreme climatic condition during planting. This might be the case in potato production in tropical highland region (700 to 2000 m above sea level) where the crop generally planted in Indonesia. According to Levy and Veilluex (2007) when planted in subtropical, semi-arid and arid regions, potato is exposed to high day and night temperatures combined with comparatively dry atmosphere. International Panel of Climate Change (IPCC) (2007) suggests that global warming affects agriculture sector and among solutions in general to minimize the effects are related to some adaptation techniques such as water storage and conservation techniques, water use, and irrigation efficiency or adjusting planting dates and crop variety and relocate crops. Current study shows that soil water content during planting is important in producing vigorous sprout growth particularly when soil temperature is at optimum level. Therefore, water management become essential for a successful crop including irrigation practices at planting (Levy and Veilluex, 2007). Vigor sprouts tend to grow into main stem and will determine the size distribution or tuber quality. However response may differ between varieties. According to Haverkort and Verhagen (2008), higher temperature and extremer water supply are two conditions that potato crop might need to adapt and breeding can play important role to obtain potato varieties that tolerant to heat stress. In addition, agronomic technology that can be considered for water conservation is mulching. Utilization of this strategy is likely to decrease the evaporation and maintain soil water and at the same time lower the soil temperature. Hamdani (2009) shows that use of straw mulch on potato planted at midland (± 680 m asl) decreased the top soil temperature at noon about 6 ^{o}C compared to control (31.5 ^{o}C) and black plastic mulch (28.5 ^{o}C).

5. Conclusion

From the current study it can be concluded that planting environment such as soil temperature and water potential interact in affecting sprout vigor of the seed tubers. This response is evident when soil temperature is at optimum level making the soil water content during planting needs to be taken into account for optimum sprout growth and vigor. The experiment justifies further examination of temperature and water potential effects on sprout number. As seed tuber physiological age has also been demonstrated to influence stem number, further experiments should assess the interaction between physiological status of the seed and the planting environment in modifying the sprouting characteristics of the seed tuber.

Reference

Beukema, H. P. and D. E. Van der Zaag. (1979). Potato Improvement Some Factors and Facts. International Agricultural Centre. Wageningen.

Fahem, M. and A. J. Haverkort. (1988). Comparison of the growth of potato crops grown in autumn and spring in north Africa. *Potato Research.* 31: 557-568.

Firman, D. M., P. J. O' Brien and E. J. Allen. (1992). Predicting the emergence of potato sprouts. *Journal of Agricultural Science.* 118: 55-61.

Grice, M. S. (1988). Physiological ages of seed potatoes. Master Thesis. University of Tasmania (*in Australia*).

Hamdani, J.S. (2009) Effect Of Mulch On Growth And Yield Of Three Potato (Solanum Tuberosum L.) Cultivars Planted In Medium Altitude. *J. Agron. Indonesia*. 37(1) : 14 – 20.

Haverkort, A. J. (1990). Ecology of potato cropping systems in relation to latitude and altitude. *Agricultural Systems.* 32: 251-272.

Haverkort, A. J. And Verhagen, A. (2008). Climate Change and its Repercussions for The Potato Supply Chain. *Potato Research*. 51: 223–237.

Heuer, B. and A. Nadler. (1995). Growth and development of potatoes under salinity and water deficit. *Australia Journal of Agricultural Research.* 46: 1477-86.

IPCC. (2007). Climate Change Synthesis Report. Viewed 12 October 2014. <http://www.ipcc.ch/pdf/assessment-report/Ar4/syr/ar4_syr.pdf>.

Iritani, W. M., D. L. Weller and N. R. Knowles. (1983). Relationships between stem number, tuber set and yield of Russet Burbank potatoes. *American Potato Journal.* 60: 423-431.

Jefferies, R. A. and D. K. L. Mackerron. (1987). Thermal time as a non-destructive method of estimating tuber initiation in potatoes. *Journal of Agricultural Science.* 108: 249-252.

Karafyllidis, D. I., N. Stavropoulos and D. Georgakis. (1996). The effect of water stress on the yielding capacity of potato crops and subsequent performance of seed. *Potato Research.* 39: 153-163.

King, B. A. and J. C. Stark. (1997). Potato irrigation management. Viewed 16 July 2005 <http://info.ag.uidaho.edu/resources/PDFs/BUL0789.pdf>.

Klemke, T. and A. Moll. (1990). Model for simulation of potato growth from planting to emergence. *Agricultural Systems.* 32: 295-304.

Knowles, N. R. and G. I. Botar. (1991). Modeling the effects of potato seed-tuber age on plant establishment. *Canadian Journal of Plant Science.* 71: 1219-1232.

Knowles, N. R. and L. O. Knowles. (2006). Manipulating stem number, tuber set, and yield relationship for northern- and southern-grown potato seed lots. *Crop Science.* 46: 284-296.

Knowles, N. R., L. Knowles and G. N. M. Kumar. (2003). Stem number and tuber set relationships for Russet Burbank, Ranger and Umatilla Russet potatoes in the Columbia Basin. *Potato Progress*, 3 (13): 1-4.

Levy, D. and R. E. Veilluex. (2007). Adaptation of Potato to High Temperatures and Salinity - A Review. *American Journal of Potato Research* 84: 487-506.

MacKerron, D. K. L. and R. A. Jefferies. (1986). The influence of early soil moisture stress on tuber numbers in potato. *Potato Research.* 29: 299-312.

MacKerron, D. K. L., B. Marshall and R. A. Jefferies. (1988). The distributions of tuber sizes in droughted and irrigated crops of potato. II. Relation between size and weight of tubers and the variability of tuber-size distributions. *Potato Research,* 31, 279-288.

Pandey S. K. (2007). Potato and Tuber Crops. Viewed 10 November 2014. <http://nsdl.niscair.res.in/handle/123456789/409>.

Pavlista, A. D. (2003). Priciples of irrigation scheduling. Viewed 1 January 2004 <http: www.panhandle.unl.edu/peyes.htm >

Reust, W., F. A. Winiger, T. Hebeisen and J.-P. Dutoit. (2001). Assessment of the physiological vigour of new potato cultivars in Switzerland. *Potato Research.* 44: 11-17.

Roy, S. K. and V. P. Jaiswal. (1997). Effect of physiological age of seed tubers on sprout growth and yield of early-planted potato (*Solanum tuberosum*). *Indian Journal of Agricultural Science.* 67: 159-160.

Stalham, M. A. and E. J. Allen. (2004). Water uptake in the potato (*Solanum tuberosum*) crop. *Journal of Agricultural Science.* 142: 373-393.

Struik, P. C. (2007b). Responses of the potato plant to temperature In Potato biology and biotechnology advances and perpective (Eds, Vreugdenhil, D., J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. MacKerron, M. A. Taylor and H. A. Ross). Elsevier. Amsterdam, pp. 367-394.

Struik, P. C. and S. G. Wiersema. (1999). Seed potato technology. Wageningen Press, Wageningen. The Netherland.

Struik, P. C., A. J. Haverkort, D. Vreugdenhil, C. B. Bus and R. Dankert. (1990). Manipulation of tuber-size distribution of a potato crop. *Potato Research.* 33, 417-432.

Svensson, B. (1977). Changes in seed tubers after planting. *Potato Research:* 20, 215-218.

Taiz, L. and E, Zeiger 2002. Plant physiology. 3rd Ed. Publisher: Sinauer Associate. England. 690 p.

Whalley, W. R., J. Lipiec, W. E. Finch-Savage, R. E. Cope, L. J. Clark and H. R. Rowse. (2001). Water stress can induce quiescence in newly-germinated onion (*Allium cepa* L.) seedlings. *J. Exp. Bot.* 52: 1129-1133.

***