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Technological Quality of Potato Tubers: Effect of Potassium Fertilization and Application Time

Research Article

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Abstract

The effect of potassium fertilization and time of application on yield and tuber quality of potato (*Solanum tuberosum* L., cv. Agria) was studied in Bekaa region in Lebanon. Potassium was applied in one split at tuber initiation (T1) and at tuber bulking (T2) in four different rates: K0 (0 kg/ha), K1 (100 kg/ha), K2 (200 kg/ha) and K3 (300 kg/ha). Results showed that aerial dry matter decreased and tuber dry matter increased during the growing period. The dry matter accumulation was dependent on potassium fertilization. Potassium concentration gradually decreased in leaves and increased in tubers during the growing period, while the most potassium treatment (K3) has accumulated at harvest, higher potassium concentrations in leaves and tubers, with more emphasis to application time T2 with respect to T1. Moreover, potassium has accelerated significantly ($p<0.05$) tuber dry matter accumulation. This was revealed by growth rate and harvest index values that were significantly higher ($p<0.05$) in K3 treatment with comparison to other treatments. Results also showed that fresh tuber yields increased with potassium fertilization and were more pronounced with T2 application whereas K3 had significantly ($p<0.05$) the highest value of 62.9 t/ha (K3). Yield augmentation was primarily due to an increase in tuber size in the larger (> 60 mm) and the medium (35 – 60 mm) grades. In addition, results showed that tuber dry matter content and specific gravity were statistically dependent on potassium fertilization and application time ($p<0.05$). The highest potassium treatment K3, regardless of application time, gave the best tuber quality of industrial potato by having the highest dry matter and the lowest reducing sugar contents. Finally, the results of this study suggest that maximum potato yield was obtained with K3 treatment (300 kg/ha) applied during tuber bulking stage (T2).

Key-words

Solanum Tuberosum L ; CV. Agria ; Potassium Fertilization; Spplication Time; Tuber Quality; Tuber Yield; Dry Matter; Potato Chips.

Introduction

Potato is the fourth most important food crop in the world after rice, corn and wheat [1]. Currently, world potato production is about 388 000 t in 2017 ; it is mainly supplied by China, India and Russia which are the main producing countrie [2]. The Mediterranean region produces 12% of the world's potato production. In Lebanon, potato was introduced in the country in the 1940s during the French Mandate [3]. At present, it is considered among the main vegetable crops. According to, the area planted with potatoes in Lebanon occupies about 12 103 ha / year, producing 257 103 t / year. The country imports 55 103 t/year for consumption, which places the potato at the forefront of lebanese vegetable imports; it exports about 81 103 t/year to bordering countries [4].

In Lebanon, the success of this crop is due to its good adaptation to the agricultural regions especially in the Bekaa, and to its important place in our diet [5]. It constitutes an essential ingredient in lebanese dishes such as fries and tradition cuisine [6]. Recently, potato has a very important role in the food industry ; processing companies producing crisps, frozen french fries, chips, dehydrated products, canned foods and ready-made meals have been developed contributing to potato marketing and the improvement of national economy [7]. However, due to the competition with potato imported from neighbor countries to meet the needs of the lebanese population, potato cultivation in Lebanon must ensure that tubers are of good technological quality.

In addition, potato quality criteria must meet market requirements (organoleptic properties, safety, nutritional value) [8]. These different aspects are closely related to the chemical composition of the tuber itself governed by several factors including potassium fertilization [9]. Potassium promotes the circulation and storage of carbohydrates, including starch in tubers [10]. It activates the ripening of tubers by synthesizing sugars and organic acids that will be transported to the tubers. This results in a higher dry matter content at harvest, which explain the decrease in water losses during storage and at the same time the increase of yield ; these criteria are very useful for industrial processing [11].

On the other hand, potato is very demanding crop for potassium [12]. Due the high cost of fertilizer-based potassium, the reasoned and efficient use of this fertilizer must be highlighted to avoid economic losses, reduce the cost of production and to achieve the necessary requirements of potato for industrial processing [13]. In some cases, the application of potassium fertilization is overestimated, and the time of application must be applied at the right stages so that the plant can assimilate the most of potassium supply [14]. To do this, a knowledge of the phenology of the plant as well as the potassium requirements according to the different phenological stages seems to be very important in order to plan a useful potato production strategy [15-16].

In order to evaluate the effects of potassium fertilization on the yield and technological quality of the industrial potato, a study was carried out on a parcel owned by a farmer in Tal-Amara and used as a demonstrated plot in the period spring - summer 2017 in collaboration Daher Agricultural Development Company specialized in potato processing. The Agria potato variety was used due to its economic importance in the field of agro-industrial processing.

Therefore, the objectives of this study aim at showing the influence of different levels of potassium fertilization on the production and technological quality of the potato (cv Agria), determining the best application time of potassium fertilizer for optimal yield and quality of tubers and studying the adaptation of the Agria variety in the pedo-climatic conditions of Central Bekaa region, Lebanon.

Materials And Methods

Location, pedo-climatic conditions

Geographic location and climate

The experimental trial was carried out in 2017 at a parcel owned by a farmer and serving for a demonstration plot at Tal Amara station in Central Bekaa (latitude N 33 º, 51 ', 44' ', longitude E 35º, 59 ', 32'', altitude 922 m). The climate of Tal Amara is semi-arid of continental type ; the winter is very short cold, not humid, and the summer is hot, very dry and extends over a long period of the year, from the month of May till the month of September. The average rainfall is 592 mm per year, concentrated between November and March [17].

The soil

The studies carried out by on the soils of Tal Amara showed a clay dominance of 44% of the granulometric composition, with a density of 1.35 g/cm3 in the first 60 cm and 1.68 g/cm3 in the depth of 60-100 cm, resulting is an average density of 1.41 g/cm3 in the depth from 0 to 100 cm [18].

According to, the soil of the experimental site is poor in organic matter, nitrogen and potassium, balanced for the other elements, rich in limestone. The normal N-P-K levels of Tal Amara soils are 70 kg/ha, 15 ppm and 400 ppm respectively.

Irrigation water

Irrigation water from Tal Amara experimental sites is brought from Terbol peripheral station, 10 km east of Tal Amara, stored in an artificial reservoir at Tal Amara before being pumped and distributed in the irrigation station network.

Plant material

The Dutch industrial potato processing variety Agria was used in our study; its vegetative cycle is 120 days. It is a medium-sized, productive variety with large tubers which is suitable for industrial processing [19].

Experimental Field

The experimental field covered an area of 1462 m2 (34 m North-South x 43 m East-West). The effective area was 963.2 m2 (22.4 m North-South x 43 m East-West). The rest of the area, ie 498.8 m2, represented the guarding of the experiment and has also been divided into two sections, each of 249.4 m2 (5.8 m North-South x 43 m East-West) surrounding the experimentation on both North and South sides. Two factors were taken into consideration in this work: the potassium rate and application time. For factor 1, four potassium treatments were differentiated: K0 was the treatment without any pure units (0 Kg/ha) of potassium; K1 was the treatment with 100 kg/ha of pure units of potassium; K2 consisted of 200 kg/ha of pure units of potassium and K3 treatment was applied with 300 kg/ ha of pure units of potassium. For factor 2, two treatments were identified: T1 was the application time at the beginning of the tuberization (60 days after sowing) whereas T2 consisted of the application at the stage of swelling of the tubers (80 days after sowing). Thus, a total of 8 treatments (K = 4, T = 2), repeated for four times, resulting in a total of 32 repetitions, each of which represents an interaction (K x T) over an area of 30.1 m2 (0.7 m North-South x 43 m South-West). The statistical plan consisted of the completely randomized block type with four large parcels or blocks, of 240.8 m^2 each (5.6 m North-South x 43 m East-West), each block contained the eight treatments.

Statistical treatments were performed using SPSS software (SPSS 10 for Windows, 1999). Analysis of the variance, ANOVA, was performed for the comparison of treatments K and T between them. The comparison of averages was made using least significant difference at $p<0.05$.

Experimentation

Pre sowing and sowing

The antecedent crop was maize, which is a good rotating head for the potato. Deep plowing of 50 cm deep was carried out in october 2016 followed by shallow plowing of 15 to 20 cm deep in early spring 2017. Seeding took place on 5 April 2017 using a sowing machine. The distance between two plants, on the same line was 25 cm and the distance between two furrows is 70 cm. This makes a density of 6 plants per m2.

Phenology

(Table 1) gives the phenological calendar of the Agria variety in number of days after sowing (d.a.s).

Table 1 : Dates of principal phenological stages of potato

Phenological stage	Date	d.a.s
Seedling	05/04/17	0
Germination	24/04/17	19
Vegetative development	01/05/17	26
Six node stage	07/05/17	32
Eight node stage	14/05/17	39
Visible Inflorescence	22/05/17	47
Complete flowering	28/05/17	53
Begining of tuber formation	04/06/17	60
Ten node Stage	11/08/17	67
Full coverage	18/06/17	74
Tuber growth	25/06/17	81
Fifteen node stage	02/07/17	88
Mature tubers	09/07/17	95
Harvest	11/08/17	128

Fertilization

The doses of N-P-K were applied to the various treatments taking into account potassium as the only variable factor. The potassium source used was potassium nitrate (KNO3) at 46% pure potassium hydroxide in the form of K_2O. Levels of potassium fertilization were chosen based on the doses used by [20]. The fertilizer application method was fertigation. Technically, potassium fertilizer can be brought without major difficulty by irrigation water, but its solubility is always lower than nitrogen. Nitrogen fertilization of 300 Kg / ha of commercial units was given in two doses simultaneously with potassium fertilization in the form of ammonium nitrate (NH_4NO_3) (33.5% N, 0% P, 0% K). To do this, a 70-liter tank, used as fertilizer mixer, was installed upstream of the irrigation system. The amounts of KNO_3 from each treatment were determined and weighed in the laboratory, dissolving them later in the mixer to be evenly distributed with the irrigation water. Potassium fertilization rates (K0, K1, K2 and K3), as well as time of fertilization inputs (T1 and T2) are summarized in (Table 2 and 3).

Table 2 : The different forms of fertilizer applied and their doses for T1 application.

Application Date	d.a.s	Treatment	Form	Dose (Kg/ha)
05/04/17 04/06/17	0 60	K0	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0% P, 0% K) Potassium Nitrate (13% N, 0% P, 46 % K)	1000 300 0
05/04/17 04/06/17	0 60	K1	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0 % P, 0% K) Potassium Nitrate (13% N, 0% P, 46% K)	1000 216 217.3
05/04/17 04/06/17	0 60	K2	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0% P, 0% K) Potassium Nitrate (13% N, 0% P, 46% K)	1000 131 434.7
05/04/17 04/06/17	0 60	K3	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0% P, 0% K) Potassium nitrate (13% N, 0% P, 46% K)	1000 47 652.1

Table 3 : The different forms of fertilizer applied and their doses for T2 application.

Application date	d.a.s	Treatment	Form	Dose (kg/ha)
05/04/17 24/06/17	0 80	K0	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0% P, 0% K) Potassium Nitrate (13% N, 0% P, 46 % K)	1000 300 0
05/04/17 24/06/17	0 80	K1	N-P-K (17, 17, 17) Ammonium nitrate (33,5% N, 0 % P, 0% K) Potassium Nitrate (13% N, 0% P, 46% K)	1000 216 217.3
05/04/17 24/06/17	0 80	K2	N-P-K (17, 17, 17) Ammonium Nitrate (33,5% N, 0% P, 0% K) Potassium nitrate (13% N, 0% P, 46% K)	1000 131 434.7
05/04/17 24/06/17	0 80	K3	N-P-K (17, 17, 17) Ammonium Nitrate (33,5% N, 0% P, 0% K) Potassium Nitrate (13% N, 0% P, 46% K)	1000 47 652.1

Irrigation Mode

Irrigation water was delivered to the plots by sprinkling till the 8-node stage (40 days after sowing). The total number of sprinklers was 12, each having a flow rate of 1.2 m^3/ hour each, ie a sprinkling of 14.4 m^3/hour was used for all the effective cultivated surface. A drip irrigation system subsequently replaced the sprinklers until harvest. The field was equipped upstream with a flowmeter to measure the amount of irrigation for use. The irrigation system was JR, with a main and side ramps spaced 70 cm apart. The distance between the drippers on the same ramp was 40 cm, and the flow rate of each dripper was 4 liters per hour at a pressure of 100 kPa. A one week watering interval was selected based on the lysimeter drainage evapotranspiration located in the middle of the plot and cultivated with potato. The surface of the lysimeter was 4 m^2 (2m x 2m). (Table 4) showed the dates of the different irrigations and the volumes of water added throughout the growth cycle.

Table 4: Calendar and volume of irrigation of potato cultivation

Irrigation date	Used Volume (m^3)	Used quantity (mm)
06-04-2017	86	58.8
20-04-2017	72	49.2
01-05-2017	100	68.4
08-05-2017	86	58.8
17-05-2017	72	49.2
24-05-2017	110	75.2
31-05-2017	130	88.9
07-06-2017	128	87.5
14-06-2017	82	56.0
21-06-2017	84	57.4
28-06-2017	84	57.4
05-07-2017	101	69.0
12-07-2017	73	49.9
19-07-2017	80	54.7
26-07-2017	69	47.2
02-08-2017	63	43.0
Total	1420	970.6

Determination of quality parameters

Aerial and underground dry matter

Measurements of the dry matter, during the various stages of plant growth (vegetative development, tuber growth, early ripening, tuber ripening and harvest), were carried out on the different treatments. For this, a batch of four plants per treatment, one plant per repetition, was sampled for the determination of aerial and underground dry matter after incubation for 48 hours at 75 ºC. The dry matter is expressed in g / plant.

Tuber growth rate

The rate of tuber growth was determined during the period between the initial and final measurements of the underground dry matter, as follows:

$$Growth\ Rate = \frac{Final\ dry\ matter - Initial\ dry\ matter}{Number\ of\ days}$$

The initial dry matter of the tubers was considered from tubular swelling. The rate of tuber growth is expressed in grams of dry matter/plant /day. This parameter reflects the rate of accumulation of dry matter in tubers.

Determination of harvest index

The harvest index HI was determined according to the following formula:

$$HI = \frac{Dry\ matter\ (tubers)}{Dry\ matter\ (plant)} \times 100$$

This parameter expresses the degree of tuber maturity.

Analysis of potassium concentration in leaves and tubers

The determination of potassium in the plant is relevant to both the aerial and underground parts. For this, the samples collected for the determination of the dry matter during the various stages of development of the plant, were retained for the determination of the potassium concentration in the leaves and the tubers. The potassium concentration is expressed as a percentage of the dry matter. The procedure used in the laboratory is as follows: the plant materials (aerial and underground) were grinded and transformed into powder. One to two grams of plant material were transfered in porcelain glasses and put in oven at 600 ºC, for 4 to 5 hours to obtain white ash. Twenty milliliters of hydrochloric acid (1 N) were added to glasses and the samples were placed in water bath for 30 minutes. Then two dillutions of 1 ml of the sample were done in 100 ml distilled water. Reading of the potassium concentration was performed using a flame photometer [21].

Determination of fresh tuber yields

Yields were determined from the fresh weight of tubers produced per unit area. It was calculated from 6 plants per longitudinal meter at 4 replicates per treatment. Yield is expressed in kg/m^2, then converted to t/ha.

Classification of tubers by size (based on ventral diameter)

The classification of the tubers was done using a manual caliper at the base of the ventral diameter of the tubers. As a result, three categories were highlighted according to: tubers of small size with ventral diameter <35 mm ; tubers of medium size between 35 mm and 60 mm and large tubers with ventral diameter> 60 mm [22].

Determination of dry matter and specific gravity

The determination of the dry matter content and the specific gravity of the tubers after harvesting was conducted using a hydrometer (densimeter) composed of a float surmounted by a graduated rod and provided at its base with a hook to attach a basket intended to contain a weight of 3,636 kg of tubers. The latter was placed in the basket which is then immersed in a tank filled with water and the dry matter content and the specific gravity value are read directly on the graduated rod at the level of the waterline.

Deterimation of glucose

Glucose is one of the most important reducing sugars that can affect the quality of potato tubers, especially the varieties for industrial processing since it can undergo maillard reaction and cause brown color [23]. This sugar was evaluated using the test strips. Three tubers of each sample were cut into two halves and the strip was placed inside the tubers for 15 seconds. The principle of the test consists of a reaction between the glucose - oxidase/ peroxidase specific to glucose. Staining occurs as a result of this reaction compared with the color scales on the label [24].

Evaluation of coloration during frying

Frying was done in order to reveal the color of the potato chips. Five tubers per sample were cut and placed on the production line and were immersed in oil at 170ºC for 6 minutes. After frying, each sample is classified in a color category in comparison to the color chart for the evaluation of the chips quality developed by the institute for conservation and processing of agricultural products in Holland. Detection was made for the presence of browning of the chips samples.

Chips tasting test

All samples from all treatments were tested by experts to to detect crispness, taste and oil absorption.

Detection of the presence of diseases and physiological accidents

At the end of the harvest, a visual examination was done by experts for the detection of external and internal diseases (parasitic agents) and internal defect (hollow heart, etc.).

Results And Discussion

Parameters of vegetative growth

Evolution of aerial dry matter

(Figures 1a and 1b) showed the evolution of potato aerial dry matter according to fertilization and potassium application time. The two figures showed that the aerial dry matter of all treatments increased gradually from the first sample carried out at flowering (54 d.a.s) to the stage of ripe tubers (109 d.a.s), where it reached for the application time T1 the values of 61.4±0.078 g; 50.0±0.021 g and 47.0 g/plant on K1, K2 and K3 treatments respectively, compared to 62 ±0.022 g/ plant of the control. For the T2 application time, these values were 47.0±0.051 g; 43.5 ±0.032g and 40.2 ±0.017 g/plant on treatments K1, K2, K3 respectively compared to the control (41.8 ±0.010 g / plant). At the end of the growth cycle, the accelerated drop in aerial dry matter on all treatments could be attributed to the defoliage and to the physiological senescence of the plant [25]. In addition, the comparison of the treatments with each other showed that the dry matter at harvest reached, on the most potassium treatment K3, the lowest values, whatever the time of application of potassium was. In fact, [12] demonstated that potassium plays an important role in photosynthesis and in the formation of chlorophyll. However, potassium content in aereal part increase with potassium intake and decrease during plant maturity. This may be due to the fact that potassium plays an important role in the mobilization and transport of assimilas from leaves to tubers [26].

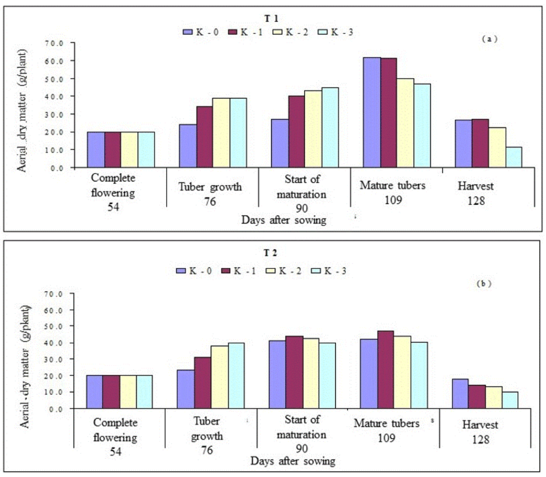

Figure 1: Evolution of aerial dry matter at T1 (a) and T2 (b)

Evolution of underground dry matter

The underground dry matter, in contrast to aerial dry matter, increases gradually from the first sampling carried out at the swelling of the tubers (76 days) to reach the values of 196 ±0.012 g at harvest; 197±0.013 g and 220±0.021 g/plant respectively on the K1, K2 and K3 treatments, compared with the control (190 ± 0.045 g/ plant) of the T1 application (Figure 2a). Compared to the T2 application (Figure 2b), these values were of the order of 170.1±0.015 g; 180.2±0.016 g and 198 ±0.026 g/plant on treatments K1, K2 and K3 compared to the control (160.3±0.035 g/plant). It should nevertheless be noted that the most potassium treatment K3 was able to accumulate for the two application times more dry matter in the tubers. This phenomenon may be attributed to potassium, which promotes the circulation and storage of carbohydrates from production sites to tubers [25, 27]. Indeed, the rate of potassium assimilation as a function of time is roughly parallel to the formation of dry matter. This absorption is however a little faster at the start of vegetation, a period when the plant seems to accumulate this cation for later needs. It is during intense vegetative activity that the need is bigger. During this period, the plant absorbs 80 to 85% of the total consumed. If the needs of the young plant appear relatively higher, the potato continues to absorb and use potassium until the harvest period [12].

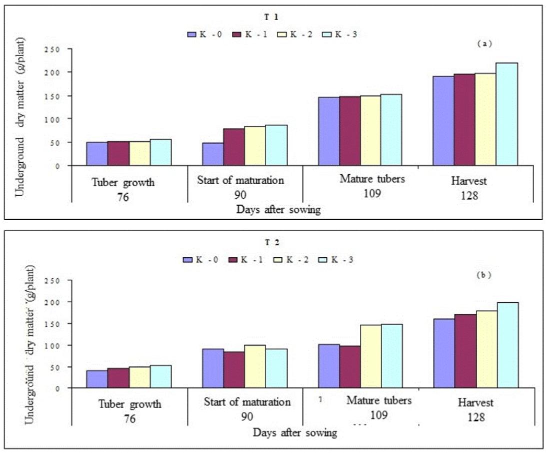

Figure 2: Evolution of underground dry matter and T1 (a) and T2 (b)

Evolution of tuber growth rate

The rate of tuber growth (Figure 3) showed the rate of filling of the dry matter of the tubers. Figure 3a showed that the rate of tuber growth was of the order of 2.69 ± 0.002 g; 2.77 ± 0.001g; 2.78± 0.011g and 3.14± 0.0018 g of dry matter per day, respectively on K0, K1; K2 and K3 treatments for T1 application time. In application time T2 (Figure 3b), these values were respectively of the order of 2.30 ± 0.015g; 2.40 g± 0.021; 2.50± 0.016 g and 2.78± 0.002 g of dry matter per day on the same treatments. These

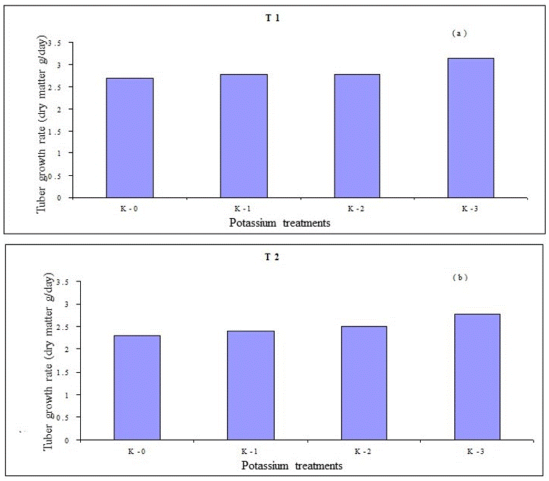

Figure 3: Evolution of tuber growth rate at T1 (a) and T2 (b)

results showed that the rate of tuber growth increases with the level of potassium fertilization as also demonstrated by [15, 25]. In fact, potassium has a important role in higher productivity of potato tubers because it has many physiological function such as the regulation of stomata activity, ensure high energy status allowing a suitable water uptake and photosynthetate translocation [12].

Evolution of the harvest index

The harvest index values of the different potassium treatments during T1 and T2 are reported in (Figure 4). For the application time T1 (Figure 4 a), the harvest index values were at the stage of swelling tubers of the order of 56 ± 0.012; 60± 0.016; 57± 0.023 and 59± 0.016% respectively on K0, K1, K2 and K3 treatments. At harvest, these values reached 86± 0.030; 87± 0.027; 89± 0.024 and 95± 0.019%, which resulted in an increase of 34.4; 31.5; 36.4 and 37.8% for the K0, K1, K2 and K3 treatments respectively between the first and the last treatment. For

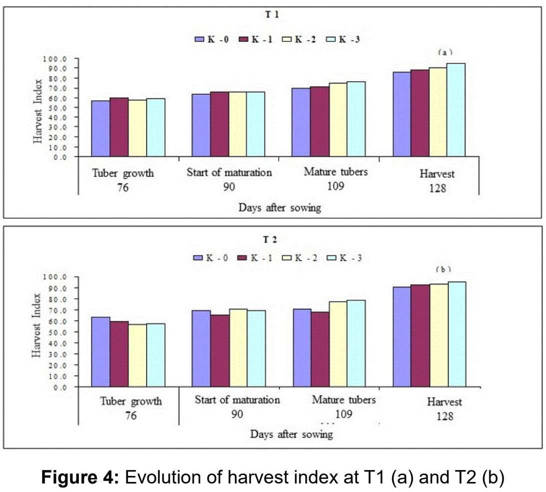

Figure 4: Evolution of harvest index at T1 (a) and T2 (b)

the T2 application time (Figure 4b), these values were 63 ± 0.017; 59± 0.019; 56± 0.022 and 57± 0.024% on the K0, K1, K2 and K3 treatments, compared with 90; 92; 93 and 95% on the same treatments respectively at harvest ; this makes an increase of 29; 35; 39 and 39% between the first and the last treatment. In conclusion, when comparing the harvest index values at harvest, an increase was observed for the T1 application time of 1.6; 3.8 and 9.2% respectively on K1, K2 and K3 treatments compared to the control. For the T2 application time, these increases were 2.4; 3.4 and 5.4% respectively on the same treatment compared to the treatment K0. The present finding are in harmony with the result of who reported that the harvest index increased with potassium dose up to 100 kg K_2O /ha in potato [28].

Evolution of the potassium content

Evolution of the potassium content in the aerial part

(Figure 5) shows that potassium content in the leaves decreased gradually with the evolution of the vegetation cycle and as the plant ages regardless of the time of application of potassium. In fact, Figure 5a showed that potassium content decreased moderately from 4.3 ± 0.001% at flowering (54 days) to values of 0.9± 0.011 %; 1.1± 0.013 %; 1.4± 0.014 % and 2.5± 0.013%, on K0, K1, K2 and K3 treatments respectively at harvest. For the T2 application time (Figure 5b), the potassium content varied from 4.3± 0.014% moderately to flowering at values of 1.8± 0.012 %; 2,3± 0.011 %; 2.3± 0.010% and 2.8± 0.014% for the same treatments at harvest. At harvest, the T2 application time treatments appeared to absorb more potassium in their leaves compared to the same T1 application time treatments. This can be explained by a

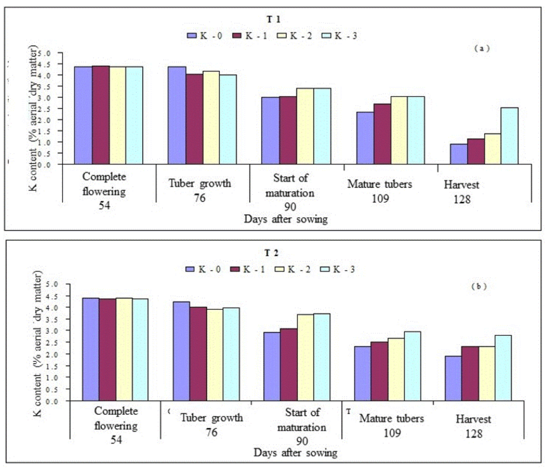

Figure 5: Evolution of potassium concentration in leaves at T1 (a) and T2 (b)

greater ability of the plant to absorb potassium in these different parts, following potassium intake given in the full stage of tubular swelling (80 days) at the beginning of tuber formation. At this point, several researchers, including have shown that potassium uptake kinetics show intense uptake from tuber initiation over a period of 30-40 days [11].

Evolution of the potassium content in tubers

(Figure 6) showed that potassium content of the tubers increased gradually during the tuber formation period. As the maturation rate increases, potassium concentrations increased so that the most potassium treatment can accumulate more potassium (2.2± 0.012%) compared to 2.1± 0.013% on the control (Figure 6a). For T2 application time (Figure 6b), the K3 treatment was able to accumulate at harvest 2.4± 0.014% of potassium whereas control had a percentage of 2.1± 0.016% of potassium in the tubers. These rates of potassium accumulation in tubers do not differ much from those found by other authors in different locations who reported that tubers with highest fertilization rate accumuate more potassium in tubers [11, 12].

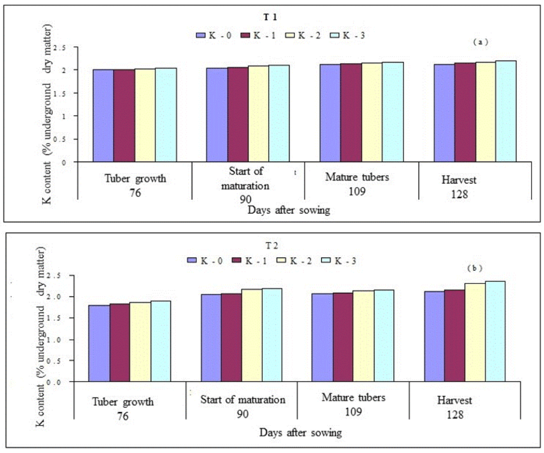

Figure 6: Evolution of potassium concentration in tubers at T1 (a) and T2 (b)

Effect of potassium fertilization on potato production

Production in fresh weight of tubers

The effect of potassium fertilization on potato production showed that it has induced an increase in fresh weight of tubers. (Table 5) showed that the increase in fresh tuber yield was proportional to the potassium dose applied. Statistical analysis showed that there is a significant difference between treatments and K3 at p <0.05. An observation made in this regard within the T1 application time showed that the control K0 produced 51.26±1.3 t/ha of fresh tubers, while the treatments K1, K2 and K3 produced 51.77±1.7; 53.92±2.1 and 55.66 ±1.9t/ha respectively. As a result, it was concluded that potassium fertilization production differences were less than 5% between the control and the two potassium levels K1 and K2, while the difference was around 8% when comparing treatment with K3 treatment. For the T2 application time, the fresh weight yield of tubers was 53.9 ±1.8 t / ha on the control K0, while on the potassium treatments K1, K2 and K3, the yields were 56.8±2.0; 58.4±2.8 and 62.3 ±1.9 t/ ha respectively. In any case, the differences in production between the control K0 and the three potassium treatments K1, K2, K3 were of the order of 5%, 8% and 14%. In addition, the comparison of the homologous potassium treatments of the two T1 and T2 application times shows that there is still a slight increase in favor of T2. Indeed, the comparison between the homologous treatments showed that there is a variation of variant production of 8 to 12% in favor of T2. Our results are in accordance with who reported the significative effect of potassium fertilization on the increase of tuber weight [12].

Indeed, potato absorbs a large quantity of potassium ; potassium deficiency lead to decreased yield production. An adequate potassium fertilization improve quality and yield as well as the vigor and general health of potato tubers [11].

Production of tubers by size (based on ventral diameter)

The effect of potassium fertilization and potassium application time on tuber size is presented in Table 5. Results showed that potassium fertilization favored for both application times T1 and T2 the tuber production of medium (between 35 and 60 mm) and large size (> 60 mm). Statistical results showed that application time of potassium has a significant effect on a less production of tubers with a diameter <35 mm. In fact, T1 application time produced fewer small size tubers (average of 0.5 t/ha) than the T2 application time (average of 1t /ha). In fact, tubers with a ventral diameter of less than 35 mm are eliminated mainly for chips production in the international market of industrial potatoes, given the technical difficulties of the transformation process [29]. Moreover, statistical results showed that potassium fertilization and application time have significant effect (p <0.05) on the production of medium and large size tubers (Table 5). However, the average production of medium-sized tubers (between 35 and 60 mm) was 26 t/ha on T1 and 30 t / ha on T2, whereas the average production of large tubers (> 60 mm) were 26 t/ ha for the two application times T1 and T2.

Our results are in accordance with who showed that the role of potassium especially at efficient dose in the translocation of carbohydrates resulting in increased tuber size [30].

Quality parameters of the potato

Dry matter and specific gravity of tubers

Specific gravity is closely related to the tuber starch content or total solids. Along wih dry matter content in tubers, they are a measure of potato quality [12].

Dry matter and specific gravity of the potassium treatments are presented in Table 6. Results showed that the dry matter of the tubers varies between 19 and 20%, whatever the level of the potassium fertilization and the time of application of potassium were. In this regard, the information given by Netherlands catalog of potato varieties, (Nivaa 1994) relates to a dry matter content of the Agria variety which is not so high (7 on a 9-point scale having an average of 6). In our experiment, potassium fertilization had an effect on the dry matter content. Indeed, for the T1 application time, the value of the dry matter of the control was of the order of 19.20 % while that of potassium treatments K1, K2, K3 were respectively 19.77; 19.5 and 20.22%. So, a simple interpretation of these results showed that the most potassium K3 treatment was able to increase by 5% in comparison with the treatment that did not receive any potassium fertilization. In the same way, the same scenario is repeated in the case of the T2 application time. Indeed, the treatment K3 could increase in this case the dry matter by 5.75% in comparison with

Table 5 : Effects of potassic fertilization and application time on fresh weight yield and tuber size

Potassium treatment	Application time	Fresh weight yield (t/ha)*	Size		
			Small <35 mm	Medium 35-60 mm	Large >60 mm
K0	T1	51.26±1.3[a]	0.59±1.4[a]	23.73±1.5[a]	19.94±1.8[a]
K1		51.77±1.7[a]	0.32±1.5[a]	23.40±1.7[a]	28.05±1.9[b]
K2		53.92±2.1[ab]	0.87±2.1[a]	24.16±1.8[a]	28.88±2.4[b]
K3		55.66±1.9[b]	0.24±2.3[a]	26.01±1.2[bc]	29.42±1.8[bc]
K0	T2	53.91±1.8[ab]	1.00±1.6[b]	27.40±2.4[a]	25.52±1.6[b]
K1		56.79±2.0[b]	1.68±1.8[b]	30.84±1.9[c]	24.27±2.8[b]
K2		58.43±2.8[c]	1.36±2.4[b]	26.95±2.0[bc]	31.13±1.7[c]
K3		62.93±1.9[c]	1.28±2.6[b]	36.46±1.5[c]	35.19±1.9[c]

**Results are mean ± SD values of four replications. For the same column, values followed by different letters within the same column are significantly different (p < 0.05)*

Table 6 : Effect of potassium treatment and application time on dry matter and specific gravity.

Potassium Treatmnt	Application Time	Dry Matter* (%)	Specific gravity*
K0	T1	19.200 ±0.001[a]	1.077±0.021[a]
K1		19.775±0.012[a]	1.079±0.034[a]
K2		19.500±0.013[a]	1.077±0.027[a]
K3		20.225±0.021[b]	1.081±0.022[b]
K0	T2	19.550±0.014[a]	1.077±0.032[a]
K1		19.175±0.015[a]	1.077±0.027[a]
K2		20.000±0.021[ab]	1.079±0.037[a]
K3		20.075±0.031[b]	1.080±0.029[b]

*Results are mean ± SD values of four replications. For the same column, values followed by different letters within the same column are significantly different (p < 0.05).

the control. Moreover, the effect of potassium fertilization and potassium application time was studied on the specific gravity of tubers whose values are shown in Table 6. Specific gravity values range from a minimum of 1.077 to a maximum of 1.081 with variability between treatments. It should nevertheless be noted that the maximum values were found on the K3 treatment for the two application times T1 and T2, with significant difference being observed on K3 treatment (Table 6). Although some authors reported that potassium fertilization has no significant effect on dry matter and specific gravity, other studies such as suggested that the both parameters were significantly affected by potassium fertilization at the highest dose applied [31-33].

Glucose content of tubers

The glucose content using test strips showed that tubers from the K0 and K1 treatments had glucose contents of 0.25%, while the most potassium treatments (K2 and K3) did not show any glucose regardless of the application time. This was revealed by the coloring of the strips following the presence or absence of glucose in the tubers. These results showed that potassium fertilization beyond a certain level, felt within the good range of recommended fertilization standards for potato and had positive effects on reduction in reducing sugars in favor of dry matter content. In deed, reducing sugars when heated react with amino acid and form maillard reaction, compounds responsible for the browning of chips which are undesirable and are consequently rejected. As mentionned by, appropriate supply of potassium reduce mechanical damage, stress tolerance and internal blackening resulting in the production of good quality of chips [23, 34].

Evaluation of coloration after frying

At the end of the frying process, chips require light yellow color showing no brown color. Our results show that all the treated samples have a very good frying color. However, samples with a high content of reducing sugars showed browning at the end of the chips after cooking. This was mainly present in samples not treated with potassium (K0) because an insufficient dose of potassium may increase the content of reducing sugars responsible for the brown coloring of the chips [10, 23].

Tasting of chips

The tasting done by the laboratory experts showed that the samples containing high dry matter contents compared to the others show a good crunchiness and crispness of the chips with a low retention of oil. As a result, samples treated with K3, the most potassium treatment, regardless of the application time, contain high levels of dry matter because it improves the technological quality while increasing the crispness of chips and reducing oil retention [23].

Detection of the presence of diseases

The potato sample were detected for diseases. Different studies showed the role of potassium in increasing the resistance of the potato to parasitic agents, while making their access to the epidermis difficult [12]. The effects of potassium fertilization on the incidence of diseases, as well as on the presence of the hollow core were investigated. It should be recalled that the hollow core which is of interest to the industrial potato, is considered one of the most remarkable defects that can affect the quality of the tubers [35]. However, the hollow heart, has not been detected in all treatments, it is perhaps due to the varietal characteristic of Agria that is not very sensitive to this internal defect according to the data of [36-37].

Conclusion

The effect of potassium fertilization on potato technological quality has been studied for the first time in Bekaa Valley in Lebanon. Results showed the rate of accumulation of dry matter, whether in the leaves or in the tubers is proportional to potassium fertilization especially in the highest potassium treatment. In addition, potassium accelerated the rate of accumulation of dry matter in the tubers, thus promoting a very high ability to feed carbohydrates from the leaves to the tubers. This was detected by the higher dry matter, growth rate in the tubers and the harvest index, which were higher in the K3 treatment for both T1 and T2 application times. On the other hand, potassium fertilization induced an increase in the production of fresh weights of tubers, which was proportional to the potassium dose applied. In addition, the comparison of the homologous potassium treatments of the T1 and T2 application times showed that the results were better with T2. Moreover, potassium fertilization favored for the two application times T1 and T2, the tuber production of the medium (between 35 and 60 mm) and large size (> 60 mm). Regarding quality parameters, dry matter of tubers and specific gravity, seems to be dependent on the dose and time of potassium application : the most potassium treatment could increase the dry matter of the tubers by 5% for T1 and by 4.75% for T2, which is considered a qualitative evolution especially when the results are reported on national scale. In this context, it is important to underline that the 5% increase in dry matter under the influence of potassium nutrition, which is significant at the 5% probability level, has a positive impact on the production and the transformation process in food industry of the potato, especially in a country like Lebanon where the potato is a strategic crop given its economic importance in the local diet.

In addition, laboratory tests have shown that less potassium treatments (K0 and K1) accumulate a higher level of reducing sugars than more potassium treatments (K2 and K3).

We can conclude that the production of the Agria variety in the pedoclimatic conditions of Central Bekaa was, no doubt, very satisfying, with a production above the level of 50 t/ha. This observation is essential for spreading this variety to other areas of potatoes grown to promote the agri-food industry of this crop. In addition, the application level of 300 kg of potassium fertilizer appeared to be the best in terms of production, especially for medium and large tubers. The best application time of potassium was at tuber swelling stage (80 days after sowing) compared to fertilization at the same dose at the beginning of tuberization (60 days after sowing).

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