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Effects of Production History and Gibberellic Acid on Seed Potatoes

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Abstract

In the present study effects of production history on tuber sprout, root, stem development and crop yield of seed potato cultivars Fambo and Van Gogh were investigated in the High Grade Area of Finland (64.9 N, 25.4 E). The haulms of seed potatoes were destroyed at the time of flowering (50 days after planting, DAP), three weeks after flowering (75 DAP) and as a control the haulm was left to natural death until harvest (95 DAP). The temperature sum accumulation of the seed potatoes was recorded for the growing season and storage period. In addition, the use of plant hormone gibberellic acid (GA) in sprout control was also investigated.

The results indicated that cultivar properties had a greater effect on the sprouting and crop yield of seed potatoes than production-phased haulm killing or temperature sum accumulation. Haulm killing carried out at three weeks after flowering (75 DAP) accelerated the emergence of both cultivars significantly compared to killing at 50 DAP or 95 DAP. Gibberellic acid (GA) treatments significantly increased the number of sprouts and at lower concentration (100 mM) GA increased the number of tubers in the cultivar Fambo. Thus, the timing of haulm killing and in the case of Fambo, GA treatment influenced the characteristics of seed potatoes produced in the present study, revealing methods to improve seed potato production in the northern latitudes.

Keywords: *Solanum tuberosum* L., haulm killing, physiological age, dormancy, storage, sprouting, emergence

1. Introduction

Seed potato quality can be measured by the ability to produce sprouts and daughter tubers. In addition to cultivar characteristics, seed quality is affected by production and storage conditions (Daniels-Lake & Prange, 2007). All these factors affect the physiological characteristics of seed potatoes. The physiological state of tubers can be assessed by accumulated temperature sum, incubation period or by combining chronological age and the incubation period (Caldiz, Fernandez, & Struik, 2001). Delaplace et al. (2008) consider the physiological age index (PAI) to be suitable for defining the aging of potato tubers. However, it has turned out to be difficult to predict physiological ageing of seed potatoes under different conditions (Johansen, Mollerhagen, & Haugland, 2008). Even though storage technologies have been developed and sprout inhibitors introduced to control the physiological state (Daniels-Lake & Prange, 2007) and sprouting, in particular, these attributes are difficult to control when seed potatoes are stored for longer periods (Kleinkopf, Oberg, & Olsen, 2003). This is the case in seed potato production areas in northern Finland (64.9 N, 25.4 E): the growing season is short (120–180 days) and the storage period is relatively long (6-8 months).

In addition, haulm killing in seed potato production is used to regulate the size of the rapidly developing tubers in order to achieve optimal tuber size distribution for commercial purposes. Haulm killing is often carried out on highly immature plants that may still be flowering and the timing of haulm killing is not synchronized with potato tuber maturation. The effect of haulm killing on the physiological state of seed potatoes cannot be predicted (Brown, Beattie, & Laurence, 2003) or the sprouting potential of tubers cannot be estimated.

One of the key quality criteria for seed potatoes is sprouting efficiency. Seed potatoes should be managed to allow sprouting at a desired time and in a desired manner (Teper-Bamnolker et al., 2010). Metabolic control of sprouting is especially influenced by the interaction of gibberellins and abscisic acid. Gibberellic acid (GA) has been found effective as an interrupter of dormancy (Salimi, Tavakkol, Hosseini, & Struik, 2010). Zabrouskov, Mohan Kumar, Spychalla, & Knowles (2002) pointed out the physiological and biochemical factors affecting seed potatoes still require further investigation. Chemical sprout inhibitors may also have phytotoxic effects (Sorce, Lorenzi, Parisi, & Ranalli, 2005).

It has been observed that sprouting management strategies are especially needed in production conditions where storage lasts several months and the growing season is short. This is especially the case in seed potato production areas in northern Finland where the influence of production history and GA treatment on sprouting control or yielding of seed potatoes have not been investigated before. We hypothesized that management strategies might differ between the cultivars with differing maturing properties. Therefore, in the present study, we investigated the effects of haulm killing as a response to temperature accumulation, and the role of GA in sprouting control on early (Fambo) and middle-late (Van Gogh) maturing cultivars of seed potatoes.

2. Method

2.1 Seed Potato Production

The seed potatoes were produced in the Tyrnävä-Liminka High Grade Area (64°N, 25°E) in the coastal area of the Gulf of Bothnia. The early cultivar Fambo and the middle-late cultivar Van Gogh were used in the study. Planting (density/row width: 28/80 cm, Kuppi-Juko, Finland) was conducted between 2 June and 7 June in four separate experimental plots (twelve plots, each comprising four replications). The preparation of field-plots was carried out according to normal cultivation practise: plowing in autumn, seedbed preparation by S-tine harrow and horizontal rotary cultivator (Juko, Finland) in spring. Before planting, soil samples were analysed (0.5 M ammonium acetate extraction, pH 4.65) and, based on the nutrition level data, 64 kg of N, 40 kg of P and 152 kg of K per hectare were applied (NPK 8-5-19 CCF). The pH and nutrient contents of soil samples varied between the plots: pH 6.5-6.6, Ca 1453-1662, P 18.8-22.3, K 89-102, Mg 113-159, Cu 3.5-3.5, Mn 13.6-14.0, Zn 1.1-1.2, S 233-388, Ca/Mg 10.45-12.86. The soil type of the field-plots was medium fine sand and the previous crop was potato. After planting, the days to emergence were recorded and the subsequent developmental stages were documented as defined by Hack et al. (1993). Temperature sums (degree days °C) were calculated using weather data provided by the Finnish Meteorological Institute, Oulunsalo weather station (64.9 N, 25.4 E). Temperature data (temperature sums, mean temperatures, precipitation) were recorded regularly (a-Weather, AWS -1.04B, Alab, Finland) for each experimental plot from the day of planting to the day of harvest (Table 1). Weed control and plant protection were uniform throughout the plots.

Table 1. The weather data representing temperature sum (degree days °C), mean temperatures and precipitation data during the experiment. The data has been collected from the official weather station [a)] and separately from the four different field plots[b)]

	Temperature sum [a)] °C	Temperature sum [b)] °C	Mean temperature [a)] °C	Mean temperature [b)] °C	Precipitation mm [a)]	Precipitation mm [b)]
June	388	359-372	12.1	13.5-13.9	35	48
July	823	712-743	18.5	16.4-17.2	57	69
August	1088	994-1006	13.6	14.1-14.6	72	63
September	1212	1117-1136	8.9	8.9-9.1	64	40

2.1.1 Haulm Killing

Mechanical haulm killing (Grimme crusher, Germany) was conducted, with the foliage cut to approximately 30 cm. Chemical haulm killing (Reglone, diquat dibromide, 200 g/l at 300l/ha) was conducted one day after mechanical haulm killing. The experimental design for the haulm killing was as follows: 1) haulm killing at the time of flowering on 22 July, 50 days after planting (50 DAP), 2) haulm killing three weeks after flowering on 14 August (75 DAP). The latter represents the normal time of haulm killing in the High Grade Area, and 3) as a control, the haulm was left to natural maturation until harvest on 2 September (95 DAP).

2.1.2 Harvesting and Storage

Harvesting was conducted ten days after haulm killing. The harvested tubers were analysed for nutrient content, weight, starch content, tuber size distribution, and external quality. The tubers were stored temporarily at +15°C until the last experimental plot was harvested. On 20 October, the total harvest from all plots was transferred to cold storage (+4°C, relative humidity 90%). Tubers sized 30–40 mm were numbered and placed in storage in egg cartons.

Cold storage (+4°C) temperatures were collected using the minimum and maximum thermometer readings and curves of the thermo-hygrograph (R Fuess Berlin-Steglitz NR. 1387, Germany). The sprouting efficiency of the seed potatoes was observed after 20 and 25 weeks of storage by counting the number of potato eyes and percentage of developed sprouts, and by measuring sprout length (categories: less than 1 cm and over 1 cm). The temperature of the sprouting environment was recorded by an automatic weather station (a-Weather, AWS -1.04B, Alab, Finland).

2.2 Carry-Over Study

After 25 weeks of cold storage (+4°C) and three weeks of pre-sprouting at +14°C, the seed potatoes were transferred to a grow tunnel and planted (5 May) in plastic growing boxes (45 cm x 60 cm) in a peat (Biolan, Novagrow) growing medium. A total of 4,680 tubers were studied (195 tubers per lot x 3 haulm killings x 4 replications x 2 cultivars). The plants were irrigated mechanically with a liquid fertilizer (Nutri S-A 0.5 ‰ solution). The temperature of the grow tunnel was recorded by an automatic weather station (a-Weather, AWS -1.04B, Alab, Finland).

The emergence dates of each individual plant were noted and the developmental stages observed according to Hack et al. (1993) with potential foliage symptoms recorded at one week intervals. Harvesting was carried out on 19 August (106 DAP). The number and fresh and dry weight of the stems and roots and the number, fresh weight, starch content and external quality of the tubers were assessed individually.

2.3 Gibberellic Acid Treatment

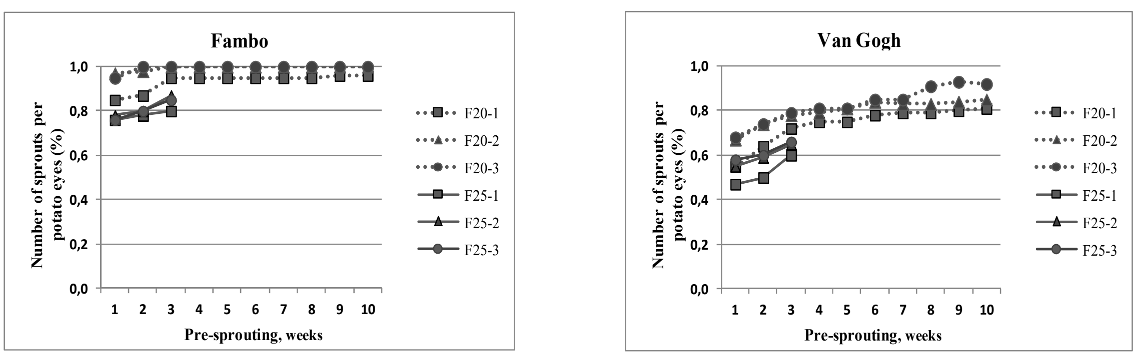
The effect of the plant hormone gibberellins (GA) on seed potato sprout development and yielding capacity was examined by immersing seed potatoes taken from cold storage in two concentrations (100 mM and 400 mM) of gibberellic acid (Sigma-Aldrich, G7645-5G, Germany) solution with one-minute water treatment as a control. After these treatments, the seed potatoes were allowed to sprout at +14°C for three weeks before planting. During pre-sprouting the number of sprouts was counted three times. At harvest, the number and weight of stems and tubers were determined individually.

2.4 Statistical Analyses

The experimental model was a split plot design with main and sub plots. The statistical analyses were conducted using the Mixed procedure of the SAS 9.2 / SAS Enterprise Guide 4.3 (SAS Institute Inc., Cary, NC, USA) program, using a variance analysis model in compliance with the split plot study design.

3. Results

3.1 Seed Potato Production



a) b)

Figure 1. The sprouting efficiency of seed tubers representing cultivars a) Fambo and b) Van Gogh after 20 (...) and 25 (__) weeks of storage. Haulm killing 1(■), at the time of flowering on July 22 = 50 DAP (days after planting), haulm killing 2 (▲), three weeks after flowering on August 14 = 75 DAP (triangle) and 3 (●) no haulm killing, natural maturation = 95 DAP

The sprouting efficiency of cultivars Fambo (p=0.58) and Van Gogh (p=0.15) differed after 20 and 25 weeks in cold storage test. The early cultivar Fambo required only three weeks of sprouting to produce the maximum number of sprouts per potato eye (%), while Van Gogh required a longer period (Figure 1).

After production, 25 weeks of storage and three weeks of pre-sprouting, the seed potatoes accumulated total temperature sums of 3,198 °C (50 DAP), 3,284 °C (75 DAP) and 3,336 °C (95 DAP). Different haulm killing times related to temperature accumulation sums or GA treatments did not result in any significant differences in the number of sprouts after three weeks of pre-sprouting.

3.2 Carry-Over Effects of Haulm Killing

Haulm killing affected the emergence of seed potatoes. Seed potatoes whose haulms were destroyed three weeks after flowering (75 DAP) emerged fastest (10.7 days), whereas those seed potatoes whose haulms maturated naturally until harvest (95 DAP) or were destroyed at the time of flowering (50 DAP) emerged more slowly (11.6-12.6 days) (Table 2). With regard to emergence rate, no significant difference was observed between the cultivars.

Haulm killing also affected the root and stem bulk produced. The physiologically older the seed potato, the larger the root and stem bulk at 95 days after planting. Root and stem bulk production was lowest in seed potatoes whose haulm had been destroyed at the time of flowering. The cultivars also differed significantly (p<0.01) with regard to root and stem bulk, with Van Gogh producing the most. Haulm killing had no effect on crop yield or the number of tubers. However, the daughter tubers of naturally maturated seed potatoes had slightly higher starch content (Table 2).

Table 2. Effect of haulm killing and cultivar (Fambo and Van Gogh) on seed potato growth vigour. Haulm killing treatments: 1) haulm killing at the time of flowering (50 DAP = days after planting), 2) haulm killing three weeks after flowering (normal time of haulm killing,75 DAP) and 3) natural maturation, no haulm killing (harvesting at 95, DAP)

						Haulm killing x Cultivar					
	Haulm killing			Cultivar		Fambo			Van Gogh		
	1	2	3	Fambo	Van Gogh	1	2	3	1	2	3
Before planting:											
No. of all sprouts	5.8	6.0	6.1	7.1**	4.8**	7.2	7.0	7.2	4.5	4.9	5.1
No. of sprouts >1 cm	1.5	1.7	1.7	1.8	1.5	1.9	2.0	1.9	1.3	1.5	1.6
After planting:											
Emergence (DAP)	12.6***	10.7***	11.6***	11.7	11.6	11.8	10.3	11.8	12.3	11.0	11.5
Harvesting:											
No. of stems	1.7	1.9	2.1	2.2	1.7	2.2	2.2	2.2	1.4	1.7	2.0
Fresh wt. of stems (g/plant)	77*	87*	119*	49*	140*	56	43	56	108	131	182
Dry wt. of stems (g/plant)	12.1*	12.4*	16.1*	10.5*	16.6*	12.0	9.6	12.0	14.2	15.2	20.3
Fresh wt. of roots (g/plant)	30.1	27.3	29.8	18.0**	40.1**	18.7	17.0	18.7	41.9	37.5	40.8
Dry wt. of roots (g/plant)	2.57*	2.36*	2.84*	1.64**	3.54**	1.68	1.56	1.68	3.45	3.16	4.01
No. of tubers	10.6	11.7	11.3	10.5	11.9	10.1	10.9	10.1	10.6	12.5	12.6
Fresh wt. of tubers (g/plant)	552	544	549	545	552	563	530	563	562	559	535
Starch content of tubers (%)	15.4*	15.0*	16.1*	13.3**	17.7**	13.8	12.8	13.8	17.5	17.2	18.4

Statistically significant differences between haulm killing treatments or cultivars at *P = 0.05, **P = 0.01 and ***P=0.001. There were no significant interactions between treatments and cultivars for any of the variables measured.

3.3 Carry-Over Effects of Gibberellic Acid

GA treatments increased the number of stems in both cultivars, with a greater effect in Fambo than in Van Gogh (p=0.001), when compared to the control treatment, even though the effect of the treatments was not found in the number of sprouts (p=0.21). The GA treatments had a negative effect on crop yield (g/plant), in particular when the cultivar Fambo was treated with 400 mM GA (p=<0.001). Correspondingly, a 100 mM GA concentration increased the number of tubers in Fambo, in comparison to water and 400 mM GA treatment, as presented in Figure 2.

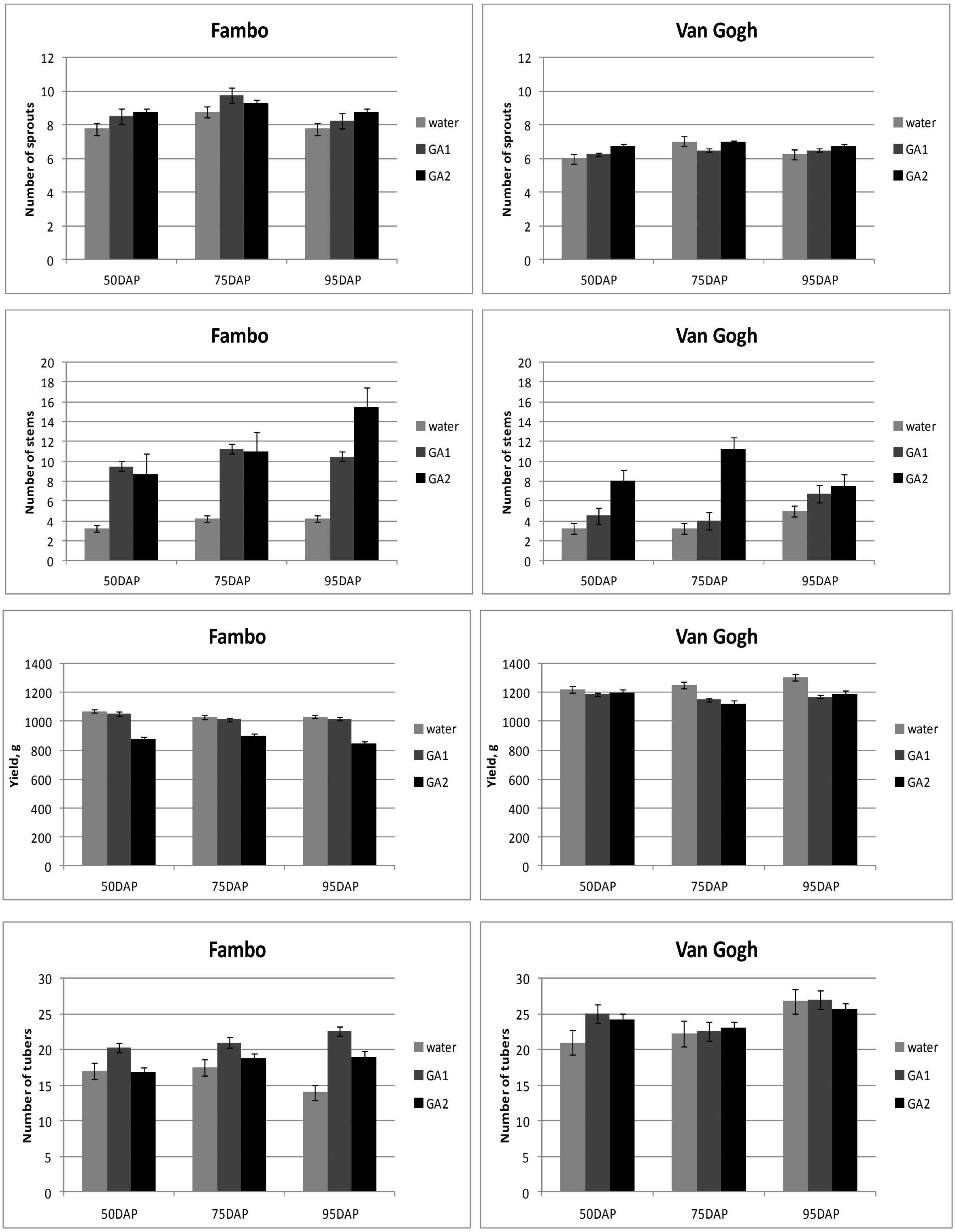


Figure 2. The effect of gibberellic acid (GA) treatments (GA1=100mM, GA2=400 mM and water control), conducted before pre-sprouting, on the number of sprouts, stems, tubers and crop of cultivars Fambo and Van Gogh. Haulm killing conducted 50 DAP (day after planting), 75 DAP and 95 DAP (harvesting 95 days after planting, no haulm killing)

4. Discussion

Seed potatoes are generally evaluated based on growth vigour and tuber productivity. In addition to cultivar, these characteristics are influenced by the production history. Northern production conditions (temperature accumulation during the growing season, short growing season, long periods of daylight, and haulm killing), storage conditions (pre-storage 2 weeks +15 °C, cold storage 25 weeks +4°C) and pre-sprouting (2 weeks +14 °C) were evaluated and all of these factors affected the growth and yielding capacity of the seed potatoes.

4.1 Effect of Production History

Temperature sum accumulation increases the physiological age of seed potato (O’Brien, Jones, Allen, & Raouf, 1986). Studies show that physiologically older seed potatoes emerge more quickly than the younger ones (O'Brien et al., 1983; Bodlaender & Marinus, 1987; Van der Zaag & Van Loon, 1987; Knowles & Botar, 1991; Jenkins, Gillison, & Alsaidi, 1993; Essah & Honeycutt, 2004; Eremeev et al., 2008). Particularly in short growing season production areas, the quick emergence of seed potatoes accelerates early development of potato growth. Haulm killing or its timing in seed potato production has not previously been observed to have a carry-over effect on the emergence rate of seed potatoes (Holmes & Gray, 1972). The present study demonstrates that in northern production conditions haulm killing conducted three weeks after flowering (75 DAP) accelerates the emergence of seed potato.

With regard to the number of stems, the results vary. In most studies, older seed potatoes produce more main stems (Iritani, 1968; Iritani & Weller, 1987; Knowles & Knowles, 2006), whereas in the studies by Ezekiel (2004), seed potato age had no influence on stem number. The timing of the temperature sum accumulation increases the number of stems in seed potato (Bodlaender & Marinus, 1987; Jenkins et al., 1993), whereas the growing season temperature and daylength do not influence the numbers of seed potato stems or bulk stems (Johansen, Lund, & Nilsen, 2002; Johansen & Nilsen, 2004). In the present study, naturally maturated seed potatoes produced the most bulk stems and roots and showed physiological behaviour similar to old seed potato.

In conditions where the growing season is short, seed potatoes that are older and that have thus experienced a higher temperature sum due to a longer accumulation period are more productive (O’Brien et al., 1983; O’Brien et al., 1986; Knowles & Botar, 1992; Ezekiel, 2004). Northern origin or daylength do not affect yield capacity (Ezekiel, 1997; Johansen et al., 2002; Knowles & Knowles, 2006; Johansen et al., 2008). On the other hand, haulm killing affects crop yield; for example, Brown et al. (2003) reported that haulm killing conducted three weeks before natural haulm maturing results in increased yield of seed potatoes. In a study by Panelo and Caldiz (1989), haulm killing two weeks before natural maturing did not affect crop yield. In the present study, haulm killing in seed potato production had no carry-over effects.

The production history of seed potato can affect the size and number of developing tubers. If the growing season is short, old seed potatoes tend to produce larger tubers than seed potatoes at younger physiological state (Jenkins et al., 1993; Johansen et al., 2002; Essah & Honeycutt, 2004; Eremeev et al., 2008). Growing season temperature has not been observed to have a carry-over effect on the number of daughter tubers produced by seed potato (Johansen et al., 2002; Johansen & Nilsen, 2004), nor has daylength been found to affect the size of daughter tubers (Johansen et al., 2002). In the studies of Wurr, Fellows, Akehurst, Hambidge, & Lynn (2001), haulm killing did not influence tuber size, and Holmes and Gray (1972) found no effect of haulm killing on tuber number. The results of the present study are consistent with Holmes and Gray (1972) and Wurr et al. (2001) indicating that haulm killing does not affect the size or number of tubers produced.

4.2 Effect of Gibberellic Acid

Salimin et al. (2010) reported that gibberellic acid (GA) was effective in interrupting the dormancy of mini-tubers. However, the sprouts that developed in the GA-treated tubers were easily broken during handling and planting. Other sprouting inhibitors are also effective in interrupting dormancy or sprouting management (Beaver, Devoy, Schafer, & Riggle, 2003; Bajji, M’Hamdi, Gastiny, Rojas-Beltran, & du Jardin, 2007; Teper-Bamnolker et al., 2010), but the effects of treatments on seed potatoes have not been studied. Alexopoulos, Aivalakis, Akoumianakis, & Passam (2008) used GA at a concentration of 1–50 mg/l and found that treatment duration appears to be more important than GA concentration. In their sprouting management studies, Pruski et al. (2006) discovered that treatment of seed potatoes with ethylene during storage resulted in larger numbers of sprouts and increased the number of tubers, but did not result in higher crop yield. Production and storage conditions (Van Ittersum 1993) as well as carbohydrate metabolism and plant hormones (Daniels-Lake & Prange, 2007) also influence dormancy. In the present study, GA treatments were in line with the results of Pruskin et al. (2006), i.e.100 mM GA concentration increased the number of tubers in Fambo but did not affect crop yield.

Sprouting management strategies and methods are particularly needed in production conditions where storage lasts several months and the growing season is short (Veerman & Wustman, 2005; Daniels-Lake & Prange, 2007). Even though the metabolism of seed potatoes (dormancy, sprouting management) can be influenced (Struik & Wiersema, 1999), the effects of production history have to be predicted and managed. In this study, the effect of northern production conditions indicate that the tubers behaved as physiologically young seed potatoes regardless of haulm killing or cultivar properties. Therefore, indicators other than tuber size are needed to determine the preferred timing of haulm killing. Also, the physiological state of tubers designated as seed potatoes should be well known in order to optimize pre-sprouting and the use of sprouting inhibitors. The timing of haulm killing and, in the case of Fambo, GA treatment influenced the characteristics of seed potatoes produced in the present study, revealing a way to improve seed potato production in northern conditions.

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