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Experiences with electrophysical desiccation in early potatoes from Rhineland-Palatinate

Erfahrungen in der elektrophysikalischen Sikkation von Frühkartoffeln in Rheinland-Pfalz

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Abstract

Electrophysical desiccation of early potatoes was tested as a non-chemical tool to reduce herbicide use. Therefore, the XPower device (Zasso®) was tested at three sites (Rhineland-Palatinate) in three trial years (2020–2022) with two driving speeds and in combinations with chemical and non-chemical desiccation tools. In addition, the role of N-fertilization and irrigation on the efficacy of electrophysical desiccation was analyzed. At 3 km h^{-1} driving speed, a higher level of leaf and stem necrosis was obtained compared to 6 km h^{-1} driving speed. The level of leaf and stem necrosis was comparable to chemical desiccation. The peel of the tubers was hardened in all desiccation treatments 14 days after desiccation. The occurrence of heel end necrosis in the electrophysical treatment was significantly reduced by increasing the driving speed and irrigation prior to desiccation.

Keywords

***Solanum tubersoum* L., peel strength, tuber quality, heel end necrosis, vascular discoloration, electrophysical vegetation control**

Zusammenfassung

Die elektrophysikalische Sikkation bei Frühkartoffeln wurde als mögliche nicht-chemische Option zur Reduktion des Herbizideinsatzes untersucht. An drei Standorten in Rheinland-Pfalz wurden in drei Versuchsjahren (2020–2022) das XPower-Gerät (Zasso®) mit zwei Fahrgeschwindigkeiten und in Kombinationen mit chemischen und nicht-chemischen Verfahren der Kartoffelsikkation geprüft. Zudem wurden die Auswirkungen von N-Düngung- und Bewässerung auf die Wirkung der elektrophysikalischen Sikkation untersucht. Bei der Geschwindigkeit von 3 km h^{-1} trat ein höherer Grad an Blatt- und Stängelnekrosen auf, während die Blatt- und Stängelnekrosen bei 6 km h^{-1} dem Niveau bei der chemischen Sikkation glichen. Die Knollen waren in 14 Tage nach der Sikkation schalenfest. Die häufiger, aber noch für die Vermarktung in vertretbarem Anteil, auftretenden Nabelendnekrosen in den elektrophysikalischen Varianten konnten durch erhöhte Fahrgeschwindigkeit und einer Bewässerung vor der Sikkation signifikant reduziert werden.

Stichwörter

***Solanum tuberosum* L., Schalenfestigkeit, Knollenqualität, Nabelendnekrose, Gefäßbündelverbräunung, elektrophysikalische Krautsikkation**

Introduction

Potatoes (*Solanum tuberosum* L.) are grown on approximately 250 thousand hectares per year in Germany, which corresponds to about 2% of the arable land (Ahrens, 2022). Despite this small proportion, this crop plays locally an important economic role for specialised farms. In particular, the cultivation of early potatoes, which are grown on sites with an early start of vegetation, offers an interesting economic option. In Germany, Palatinate is the main location for early potato cultivation. Early potatoes are defined as 'potatoes harvested before they are completely mature, marketed immediately after their harvesting, and whose skin can be easily removed without peeling' (UNECE, 2021). To promote uniform ripening, to induce proper skin set and to prevent the transmission of viral diseases from the leaves to the tubers, desiccation is commonly used in early potatoes production. Furthermore, it facilitates harvesting and decreases skinning injury (Lulai & Orr, 1993; Kempenaar & Struik, 2007). Different desiccation programs, which are well established methods for defoliation, have been proven. Mechanical methods for desiccation are performed e.g., with a flail beater, which is often used in organic production. The mechanical methods do not always achieve a sufficient effect on the haulm, especially in conditions with strong vegetative growth (Boydston et al., 2018). Therefore, desiccation programs with a sequence of methods are common. In contrast to mechanical methods, chemical desiccation is less labour and cost intensive (Kempenaar &

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Struik, 2007). For this purpose, contact herbicides like carfentrazone-ethyl, pyraflufen-ethyl, pelargonic acid or diquat are used (Zotarelli et al., 2016). The bipyridine diquat, which was mainly applied in the past, is no longer available for desiccation in Europe (Commission implementing regulation (EU) 2018/1532, 2018). In general, a paradigm shift in plant protection towards more non-chemical alternatives is emerging (Waldmann, 2021). Alternatives need to be evaluated to implement this paradigm shift. A long disregarded non-chemical tool represents the electrophysical vegetation control. Timmons (2005) cites early records suggesting to use electricity to control Johnsongrass (*Sorghum halepense* L.) as early as 1901. In the 1940s an attempt was made to promote the "electrovator", a device designed to emit electrical charge into plants, but was ultimately considered ineffective in perennial weed control. In the 1980s, experiments were carried out with electricity to control bolters of sugar beet with promising success. Due to technical reasons and low market opportunities, this device was not further developed (Diprose et al., 1985). To offer non-chemical-alternatives, use of electrophysical systems is one option for desiccation in potatoes. In 2016, Zasso® introduced the Elctroherb™ technology with the XPower device. In 2020, the first prototypes of the XPower system were supplied and tested. The XPower system includes a generator unit and an application unit. The generator, which is connected at the rear of the tractor, supplies 230 V alternating current and converts it to 700 to 8000 V direct current by rectifier circuits mounted on the applicator. The applicator consists of three rows of electrodes (two positive and one negative), which touch the plants during application. The version used in the presented study had a working width of 3 m and provides a maximum output power of 72 kW (Koch et al., 2020). However, little is known on the integration of electrophysical systems in cultivation practices to date.

The objective of this study was to evaluate the efficacy of the Electroherb™ technology with the XPower device for the desiccation of early potatoes..

The following hypotheses were tested:

1. The haulm can be sufficiently desiccated by Electroherb™ technology with the XPower device system.
2. The efficacy of electrophysical desiccation is comparable to the efficacy of chemical desiccation.
3. Higher N-fertilization reduces the efficacy of the electrophysical system.
4. Dry soil conditions increase the proportion of tubers with reduced internal quality.

Material and Methods

Experimental Setup

For all field trials, the Electroherb™ technology, was used. Field trials were conducted at three sites in Rhineland-Palatinate: in Bingen am Rhein, Frankenthal and Mutterstadt, from 2020 to 2022. Planting date, N-fertilization and irrigation during the vegetation period differed between the field sites (Table 1). The different desiccation programs were conducted in BBCH 69–70. In 2020, potato varieties differ between the locations. In the following years 2021 and 2022, all investigations were focused on the variety 'Musica'. The planting distance of the tubers ranged between 33 and 38 cm. N-Fertilization was performed using stabilised urea fertiliser in Bingen and mixed fertiliser (N-content: 50% by weight both ammonium and nitrate) in Mutterstadt and Frankenthal. The entire N fertilizer was applied before planting.

The precipitation and the temperature were similar between the sites in the corresponding years (Table 2). During the growth period in the years 2020 and 2022, less precipitation fell than in 2021. Less precipitation was highly associated with higher temperature.

Eight different treatments were performed in the field trial in Bingen (Table 3). Two different driving speeds of XPower (3 and 6 km h^{-1}), two combinations of flail beater followed by 6 km h^{-1} XPower as well as 6 km h^{-1} XPower followed by a herbicide I, a herbicide sequence consisting of two applications, driving speed with 3 km h^{-1} and additional N-supply and driving speed with 3 km h^{-1} without irrigation before desiccation were compared to an untreated control. Flail beating was simulated by cutting the haulm 5 cm above the potato ridge five days before electrophysical desiccation. Different nitrogen-levels were investigated, because higher levels of nitrogen exacerbate the haulm desiccation (Ivany et al., 1986). The

Table 1. Variety, planting date, nitrogen fertilization, irrigation and date of desiccation depending on the site and year

Site	Year	Variety	Planting date	N-level (kg ha^{-1})	Irrigation (l m^{-2})	Date of desiccation
Bingen	2020	Anabelle	20 Feb	120[a]	110[b]	24 Jun
Bingen	2021	Musica	25 Feb	120[a]	150[b]	8 Jul
Bingen	2022	Musica	28 Feb	120[a]	160[b]	7 Jun
Frankenthal	2020	Ivona	1 Apr	157	150	25 Jun
Frankenthal	2021	Musica	9 Apr	187	120	20 Jul
Frankenthal	2022	Musica	1 Apr	170	150	23 Jun
Mutterstadt	2020	Ivona	24 Mar	173	175	25 Jun
Mutterstadt	2021	Musica	22 Mar	187	195	20 Jul
Mutterstadt	2022	Musica	22 Mar	186	195	23 Jun

[a] 170 kg N ha^{-1} in one treatment
[b] drip irrigation

Table 2. Precipitation and temperature from March to July, depending on site and year

Site	Year	Precipitation [L m^{-2}]					
		March	April	May	June	July	Sum
Bingen[a]	2020	35	13	36	28	10	122
	2021	19	17	51	68	90	245
	2022	28	26	27	65	2	148
Frankenthal[b]	2020	32	7	23	76	24	162
	2021	21	17	65	110	73	286
	2022	19	53	18	47	13	150
Mutterstadt[c]	2020	33	9	32	81	27	182
	2021	22	17	41	118	67	264
	2022	14	63	19	53	21	170

Site	Year	Temperature [°C]					
		March	April	May	June	July	Average
Bingen[a]	2020	7.5	12.3	14.1	18.6	20.7	14.6
	2021	6.5	8.1	11.9	20.7	19.5	13.3
	2022	6.4	9.7	16.7	20.2	22.1	15.0
Frankenthal[b]	2020	7.7	13.0	14.5	18.5	21.0	14.9
	2021	6.9	8.4	12.6	20.9	19.9	13.7
	2022	7.1	10.1	17.6	20.8	22.4	15.6
Mutterstadt[c]	2020	7.9	13.4	15.1	18.9	21.1	15.3
	2021	6.8	8.5	12.8	21.1	20.0	13.9
	2022	7.0	10.1	17.8	21.1	22.3	15.7

[a] weather station Bingen Gaulsheim
[b] weather station Frankenthal-Eppstein
[c] weather station Mutterstadt

Table 3. Description of the desiccation treatments conducted at Bingen in 2020, 2021 and 2022

Treatment	Desiccation program	Leaf desiccation	Stem desiccation	Speed during electrophysical application (km h^{-1})	Irrigation before electrophysical application (L m^{-2})[d]
1	Control	-	-	-	10
2	Electrophysical	Electrophysical	Electrophysical	3	10
3	Electrophysical	Electrophysical	Electrophysical	6	10
4[a]	Combination	Flail beater	Electrophysical	6	10
5	Combination	Electrophysical	Chemical[b]	6	10
6	Chemical	Chemical[c]	Chemical[b]		
7	Electrophysical	Electrophysical	Electrophysical	3	-
8[e]	Electrophysical	Electrophysical	Electrophysical	3	10

[a] not in 2020
[b] 1.0 L ha^{-1} Shark® (microemulsion, 60 g l^{-1} carfentrazone-ethyl (HRAC: 14))
[c] 0.8 L ha^{-1} Quickdown® (emulsion concentrate, 24.2 g l^{-1} pyraflufen (HRAC: 14)) + 2.0 l ha^{-1} Toil® (adjuvant)
[d] drip irrigation
[e] + 50 kg N ha^{-1}

maximum direct current of 8000 V was used for all trials. All herbicides for chemical desiccation were applied with a one-wheel plot sprayer (Baumann Saatzuchtbedarf, Germany; air mix 120-05 flat fan, spray pressure 210 kPa, spray volume 400 L ha^{-1}, speed 4.5 km h^{-1}) with a working width of 3 m.

In Frankenthal and Mutterstadt, only four treatments were performed (Table 4). The fields were provided by two potato producers annually.

Each treatment was repeated four times in all trial years. The plots (20 m × 3 m, i.e., four rows with 0.75 m width) were allocated using a randomized block design.

The soil moisture was measured shortly before the electrophysical desiccation using the TDR Fieldscout 350 (Spectrum Technologies, 3600 Thayer Court, Aurora). The plots in Frankenthal and Mutterstadt were not irrigated before the electrophysical desiccation (Table 5).

Assessment of desiccation efficacy and tuber quality

To assess the efficacy of the XPower system and the other desiccation measures, the percentage of necrosis tissue was estimated visually 7 and 14 days after the last desiccation treatment separately for leaf and stem tissue. In addition, re-sprouting was monitored.

Tuber samples were taken from 20 plants per plot, 7 and 14 days after last desiccation treatment. The samples were sorted with sieves with mesh sizes of 30 and 60 mm and grouped in three tuber fractions with diameter sized of less than 30 mm, 30 to 60 mm and more than 60 mm. Tubers of the fraction 30 to 60 mm were used for subsequent assessments. Starch content was analyzed with the under-water weight method. Therefore, 5 kg tubers were washed. The calculated specific gravity (equation 1) was used to determine the starch content of the tubers (%) according to Lunden (1956) (equation 2).

$$specific\ gravity = \frac{5000}{(5000 - underwater\ weight)} \quad (1)$$

$$starch\ content\ (\%) = -211.89 + 209.06 * specific\ gravity \quad (2)$$

The hardness of the tuber skin of 40 randomly selected tubers was tested separately for each sample. A scoring system was used to quantify, how easily the skin can be removed (Table 6). Even-numbered scores were assigned for transitions.

The same 40 tubers were used for the internal quality assessment. The tubers were halved to identify vascular discoloration and necrotized heel end. Both are symptoms that can occur due to desiccation (Headford & Douglas, 1967). A scoring system was used to validate the incidence as well as the severity of both symptoms separately (Table 7). Even-numbered scores were assigned for transitions.

Table 4. Description of the desiccation treatments conducted at Frankenthal and Mutterstadt in 2020, 2021, 2022

Treatment	Desiccation program	Leaf desiccation	Stem desiccation	Speed during electrophysical application (km h^{-1})
1	Control	-	-	-
2	Electrophysical	Electrophysical		6
3	Electrophysical	Electrophysical		3
4[a]	Combination	Flail beater	Electrophysical	6

[a] not in 2020

Table 5. Soil moisture in 0-12 cm depth [volume water content (VWC), %] before electrophysical desiccation depending on the trial year and trial site, averaged for the specific field (n.a. = not available)

Trial year	Trial site	Soil moisture [VWC, %] ridge valley		Soil moisture [VWC, %] top of the ridge	
		Irrigated before desiccation	Non irrigated before desiccation	Irrigated before desiccation	Non irrigated before desiccation
2020	Bingen	27.47	25.90	13.72	16.10
	Frankenthal		30.39		15.77
	Mutterstadt		32.40		14.61
2021	Bingen	25.59	25.84	14.64	14.07
	Frankenthal		10.67		12.86
	Mutterstadt		10.62		9.87
2022	Bingen	20.63	16.27	11.50	7.53
	Frankenthal		n.a.		n.a.
	Mutterstadt		n.a.		n.a.

Table 6. Explanation of the scoring system used for the assessment of the hardness of the tuber skin

Score	Explanation
1	Tuber skin cannot be removed with the thumb
3	Tuber skin is removable with the thumb
5	Tuber skin can be easily removed with the thumb
7	Tuber skin begins to loosen from the flesh without any external influence
9	Tuber skin loosen from the flesh without any external influence

Table 7. Explanation of the scoring system used for the assessment of the severity of vascular discoloration and necrotized heel end

Score	Explanation for vascular discoloration	Explanation for necrotized heel end
1	Vascular ring invisible	No necrotized heel end
3	10–20% of the vascular ring is brown	Only initial part of heel end necrotized
5	40–50% of the vascular ring is brown	Necrotized heel end
7	70–80% of the vascular ring is brown	Area around the heel end necrotized
9	90–100% of the vascular ring is brown	Parts of the pith necrotized

Statistical analysis

Statistical analysis was conducted with R, version 4.2.3 (R Core Team, 2023). All data were tested for normal distribution (Shapiro-Wilk test) and variance homogeneity (Levene test) using the R package *car* (Fox & Weisberg, 2019). Subsequently, a linear mixed effects model (LMM) was used to analyze the effect of the desiccation method (fix effect). For the treatments 1–4 (see Tables 3 and 4), which were performed at all sites and years, a LMM with two random factors (site and year) were carried out for all responsible variables. Only one random factor (year) was included in the LMM for the treatments 5–8, which were only performed in Bingen. Following responsible variables were analyzed: efficacy on leaf and stem tissue, starch content and the tuber size distribution. Furthermore, the effect of treatment on the proportion of tubers with vascular discoloration and necrotized heel end was tested. Adding the measured values of soil moisture as further factor, did not lead to any further explanations for the responsible variables proportion of tubers with vascular discoloration and necrotized heel end. The factor irrigation scenario with two factor levels ("irrigated", "non-irrigated") was included as fix effect. The package *lmerTest* was used for LMM (Kuznetsova et al., 2017). After the LMM, Tukey's honestly significant difference (HSD) post hoc test ($\alpha \leq 0.05$) was conducted by using the package *emmeans* (Lenth, 2023). Due to the ordinal scaled scores for the severity of the vascular discoloration, the necrotized heel end and the scores for the peel hardness, a non-parametric Kruskal-Wallis test was applied. Subsequently, a Nemenyi post hoc test was conducted. For both tests, the *PMCMRPlus* package was used (Pohlert, 2022).

Results

The efficacy of electrophysical desiccation was analysed for all three sites and years. Averaged over all years and sites, the leaves of potatoes treated by electrophysical desiccation were more necrotized 14 days after treatment compared to the untreated control (Fig. 1). No significant differences were observed between the desiccation programs for the leaf tissue. However, a speed of 6 km h^{-1} reduced the proportion of the necrotized stem tissue compared to 3 km h^{-1}. No resprouting was observed in the trials.

In addition to the electrophysical treatments performed at all trial sites, efficacy of chemical desiccation, of additional N treatment and of irrigation were tested in Bingen only. No significant differences in necrotized tissue were found between different N-levels and irrigation scenarios at a speed of 3 km h^{-1} (Fig. 2). Furthermore, the combination of two chemical desiccants or chemical and electrophysical desiccation did not show a significant increase in necrotized tissue.

No differences in tuber yield were ascertained between all treatments (data not shown). The average total tuber yield was approximately 39 t ha^{-1} and the marketable tuber yield approximately 35 t ha^{-1}.

The peel strength was analysed for all three sites and years. The score for peel strength was significantly higher for the untreated control compared to desiccated treatments (Table 8). For the first assessment 7 days after desiccation, electrophysical desiccation had higher scores compared to the chemical desiccation program. Fourteen days after the desiccation, the scores of all treatments were similar.

The internal quality was assessed for all sites and treatments. Highest proportion of tubers with necrosis was assessed after treatment with 3 km h^{-1} driving speed. In general, electrophysical desiccation led to higher proportions of tubers with necrotized heel end (Fig. 3). Fourteen days after desiccation, no significant difference between all treatments was shown for the proportion of tubers with vascular discoloration.

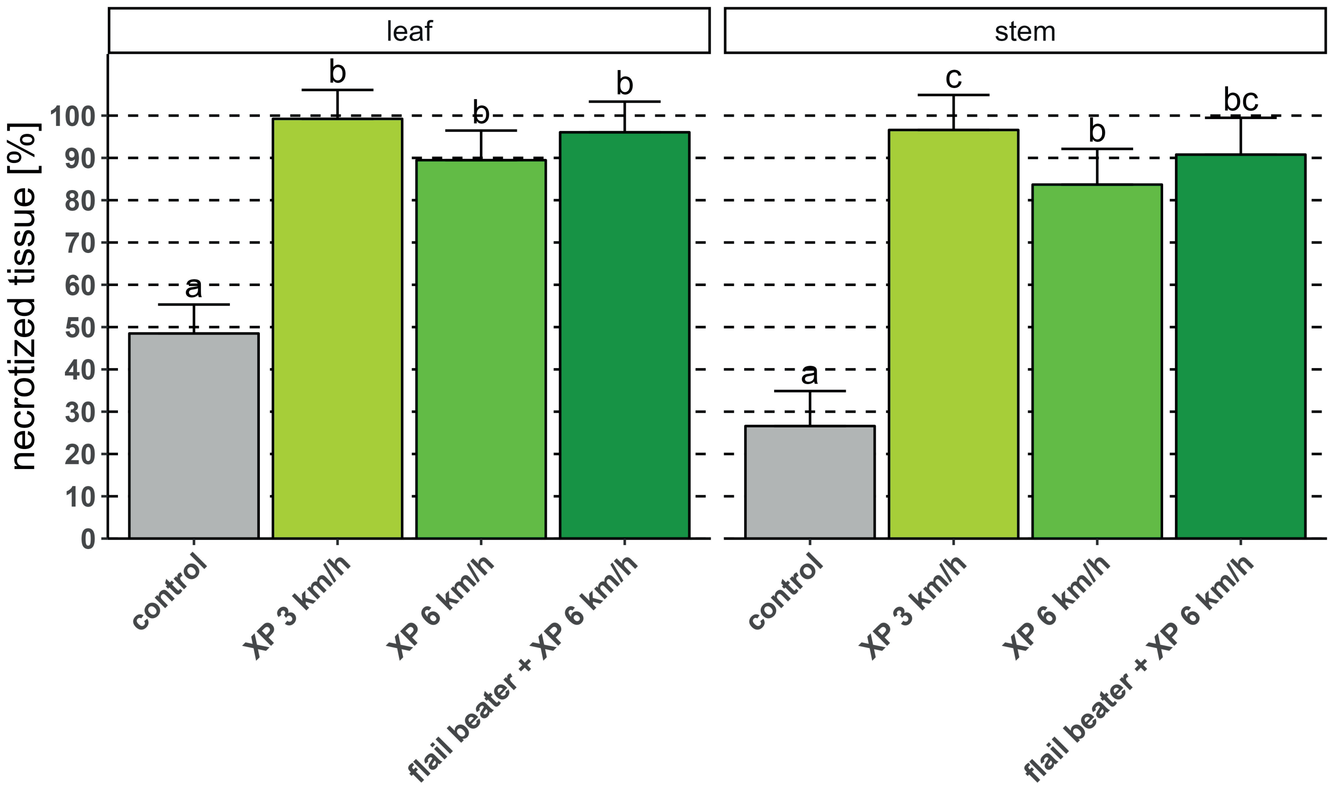

Fig. 1. Necrotized tissue [%] of leaf (left) and stem (right) 14 days after desiccation of potatoes, for all three trial years and sites (Bingen, Frankenthal and Mutterstadt),different letters indicate significant differences between desiccation program, $p \leq 0.05$, Tukey HSD test

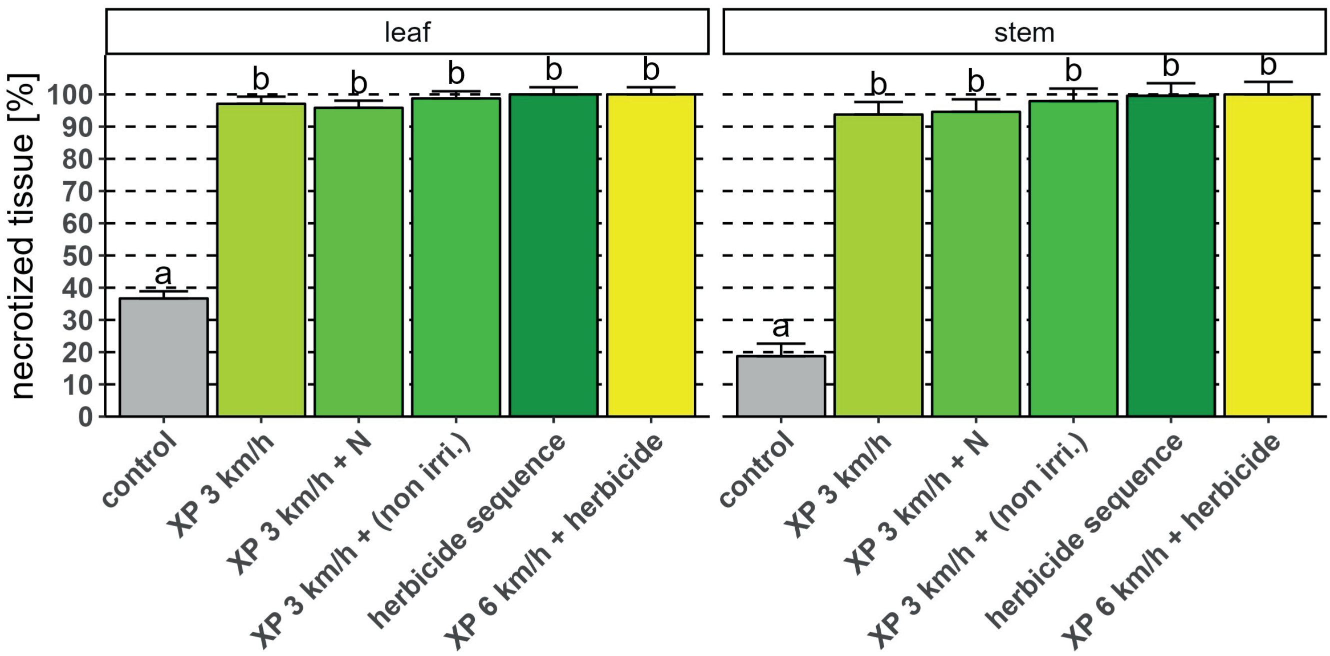

Fig. 2. Necrotized tissue [%] of leaf (left) and stem (right) 14 days after desiccation of potatoes, for all three trial years at the site Bingen (+N: additional 50 kg N ha^{-1}, non-irri.: non irrigated before desiccation, herbicide sequence: 0.8 L ha^{-1} Quickdown® + 2.0 l ha^{-1} Toil ® +: 1.0 L ha^{-1} Shark®, in combination with electrophysical treatment only 1.0 L ha^{-1} Shark®), different letters indicate significant differences between desiccation treatment, $p \leq 0.05$, Tukey HSD test

In Bingen, irrigation before desiccation significantly reduced the proportion of tubers with necrotized heel ends, but not the degree of vascular discoloration (Fig. 4).

The scores of necrotized heel end differ significantly between the treatments 7 and 14 days after desiccation, with lowest scores in the control group (Table 9). The vascular discolor-

Table 8. Score of peel strength 7 and 14 days after desiccation (DAD) of potatoes for treatments conducted at all sites (All) and treatments only conducted at Bingen (Bingen), different letters indicate significant differences between desiccation program, $p \leq 0.05$, Nemenyi test)

DAD	Site(s)	Desiccation program	Averaged score	S.E.	Significance level
7	All	Control	3.0	0.7	B
		3 km h^{-1} XPower	2.2	0.7	A
		6 km h^{-1} XPower	2.0	0.7	A
		Flail beater + 6 km h^{-1} XPower	2.0	0.7	A
7	Bingen	Control	4.2	0.7	b
		3 km h^{-1} XPower	3.5	0.7	ab
		3 km h^{-1} XPower + N	3.7	0.7	ab
		3 km h^{-1} XPower (non irri.)	3.6	0.7	ab
		6 km h^{-1} XPower + chemical[b]	2.9	0.7	a
		chemical[a] + chemical[b]	2.9	0.7	a
14	All	Control	2.3	0.3	B
		3 km h^{-1} XPower	1.3	0.3	A
		6 km h^{-1} XPower	1.5	0.3	A
		Flail beater + 6 km h^{-1} XPower	1.4	0.4	A
14	Bingen	Control	2.6	0.4	a
		3 km h^{-1} XPower	1.7	0.4	a
		3 km h^{-1} XPower + N	1.6	0.4	a
		3 km h^{-1} XPower (non irri.)	1.7	0.4	a
		6 km h^{-1} XPower + chemical[b]	1.6	0.4	a
		chemical[a] + chemical[b]	1.5	0.4	a

[a]0.8 L ha^{-1} Quickdown® + 2.0 L ha^{-1} Toil®
[b]1.0 L ha^{-1} Shark®

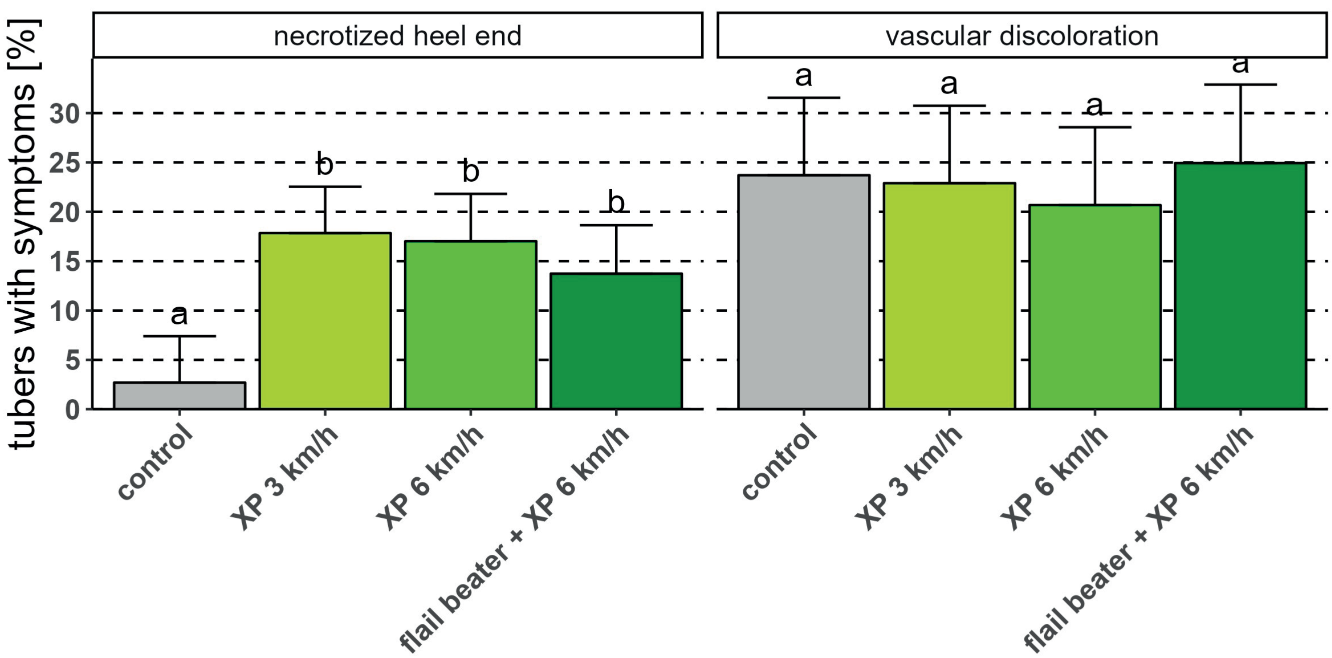

Fig. 3. Potato tubers with necrotized heel end or vascular discoloration [%] 14 days after desiccation, for all three trial years and sites (Bingen, Frankenthal and Mutterstadt), different letters indicate significant differences between desiccation programs, $p \leq 0.05$, Tukey HSD test

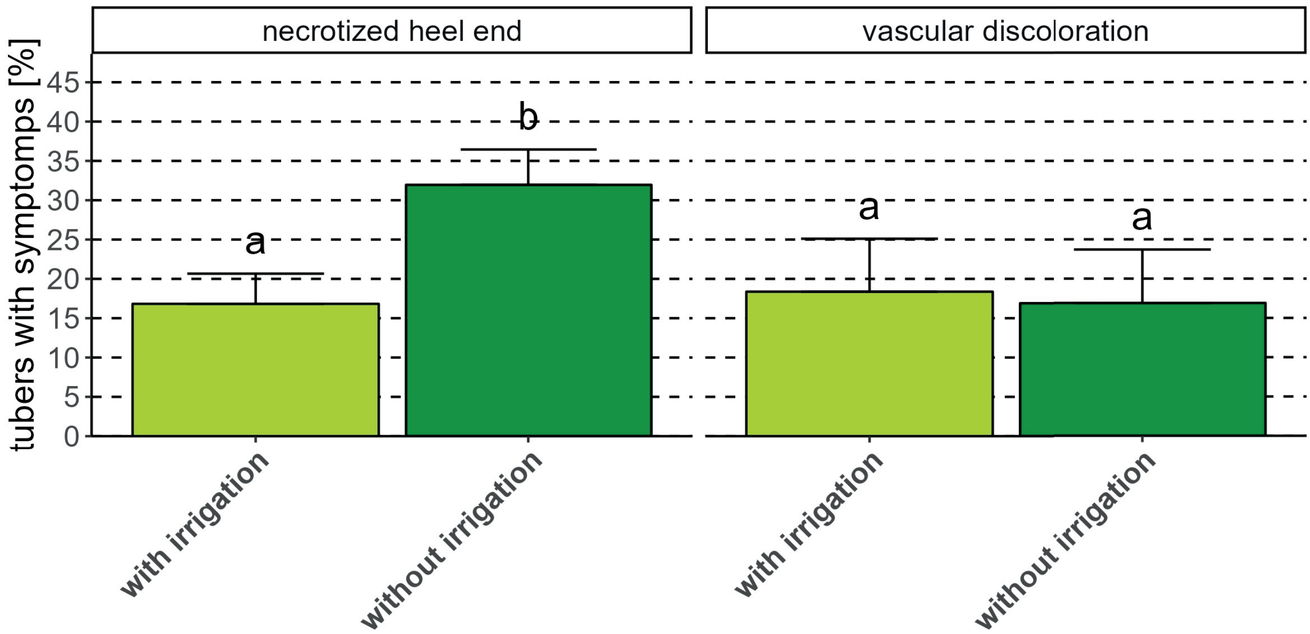

Fig. 4. Potato tubers with necrotized heel end or vascular discoloration [%] 14 days after desiccation, for all three trial years at the site Bingen, different letters indicate significant differences between irrigation scenario, $p \leq 0.05$, Tukey HSD test

Table 9. Scores for necrotized heel end and vascular discoloration of the potato tubers 7 and 14 days after desiccation (DAD) on different sites, different letters indicate significant differences between desiccation program, $p \leq 0.05$, Nemenyi test

DAD	Site(s)	Desiccation program	Necrotized heel end			Vascular discoloration		
			Averaged score	S.E.	Significance level	Averaged score	S.E.	Significance level
7	All	Control	1.0	0.1	A	1.4	0.2	A
		3 km h^{-1} XPower	1.3	0.1	B	1.4	0.2	A
		6 km h^{-1} XPower	1.1	0.1	AB	1.4	0.2	A
		Flail beater + 6 km h^{-1} XPower	1.2	0.1	AB	1.4	0.2	A
7	Bingen	Control	1.0	0.1	a	1.1	0.1	a
		3 km h^{-1} XPower	1.1	0.1	a	1.1	0.1	a
		3 km h^{-1} XPower + N	1.1	0.1	a	1.1	0.1	a
		3 km h^{-1} XPower (non irri.)	1.3	0.1	b	1.2	0.1	b
		6 km h^{-1} XPower + chemical[b]	1.2	0.1	ab	1.2	0.1	ab
		chemical[a] + chemical[b]	1.1	0.1	a	1.1	0.1	a
14	All	Control	1.0	0.1	A	1.4	0.1	A
		3 km h^{-1} XPower	1.3	0.1	B	1.4	0.1	A
		6 km h^{-1} XPower	1.4	0.1	B	1.3	0.1	A
		Flail beater + 6 km h^{-1} XPower	1.2	0.1	B	1.4	0.1	A
14	Bingen	Control	1.1	0.1	a	1.4	0.2	a
		3 km h^{-1} XPower	1.5	0.1	ab	1.4	0.2	c
		3 km h^{-1} XPower + N	1.5	0.1	ab	1.4	0.2	bc
		3 km h^{-1} XPower (non irri.)	1.7	0.1	b	1.4	0.2	c
		6 km h^{-1} XPower + chemical[b]	1.6	0.1	b	1.4	0.2	c
		chemical[a] + chemical[b]	1.2	0.1	a	1.4	0.2	ab

[a]0.8 L ha^{-1} Quickdown® + 2.0 L ha^{-1} Toil®.
[b]1.0 L ha^{-1} Shark®

ation scores did not differ significantly between the treatments.

Tubers of non-desiccated plants had the highest starch content in both assessments (Fig. 5). A speed of 6 km h^{-1} during the electrophysical application led to a significant higher starch content compared to 3 km h^{-1}.

Discussion

The aim of the presented study was to evaluate the use of the electrophysical Electroherb™ technology with the XPower device in desiccation of early potato.

The presented study showed that the haulm of early potatoes can be sufficiently desiccated by the Electroherb™ technology with the XPower device system (hypothese 1). Furthermore, the efficacy of this electrophysical desiccation was comparable to the efficacy of chemical desiccation (hypothese 2).

However, higher stability in efficacy was observed at a driving speed of 3 km h^{-1} during the electrophysical application compared to a driving speed of 6 km h^{-1}. This can be attributed to longer contact duration between haulm and electrodes at the lower driving speed. Electrophysical applications at 6 km h^{-1} led to a higher starch content in the tubers compared to the chemical desiccation or electrophysical desiccation at 3 km h^{-1}. This indicates a delayed dieback process of the green potato material due to less electrode contact of the plants. The higher desiccation intensity in response to slower speed was not required in all situations. Four factors are relevant to determine the driving speed and thus the intensity of this electrophysical desiccation: (1) Timing of the desiccation and the associated maturity of the haulm plays a crucial role for the intensity needed for each desiccation method (Halderson et al., 1985). Higher speed is possible for haulm with incipient maturity. In line with this, 6 km h^{-1} driving speed was sufficient for successful desiccation at Bingen in 2020. In the following year, the delayed maturity of the plants exacerbated the desiccation. (2) In addition to haulm maturity, aboveground biomass, determined by potato variety genetics and environmental conditions, also influenced the efficacy of each treatment. Varieties with dense leaf canopy and good growth conditions require a more energy-intensive desiccation treatment then varieties growing less or grow under unfavorable conditions. In this study, only three varieties were grown. However, we assume that varieties that require higher intensity in chemical desiccation also require higher intensity in electrophysical desiccation. (3) Environmental conditions must be suitable for desiccation. Technologies like Electroherb™ target the vascular system of the plant and serve to initiate the wilting process. In 2021, precipitation before and after the desiccation treatments led to a delayed dieback of the potato plants. Due to higher humidity on haulm surface, the efficacy appears to be lowered. The reduced concentration of the electric energy in the targeted tissue could explain the delayed dieback process. (4) If electrophysical treatments are embedded in desiccation sequences with chemical or mechanical treatments, a driving speed of 6 km h^{-1} led to comparable results compared to the single treatment with 3 km h^{-1} (Fig. 3). However, a desiccation sequence consisting of e.g. flail beater with subsequent electrophysical treatment seems to be an extremely energy-intensive alternative compared to the application of chemical desiccants.

Our third hypothesis postulated that higher N-fertilization reduced the efficacy of electrophysical desiccation. The driving speed of 3 km h^{-1} seems to be appropriate for potato desiccation over a wide range of different conditions, such as the N-level or biomass, which must be desiccated (Fig. 2). Despite a partly delayed maturity at higher N-levels, no differences in

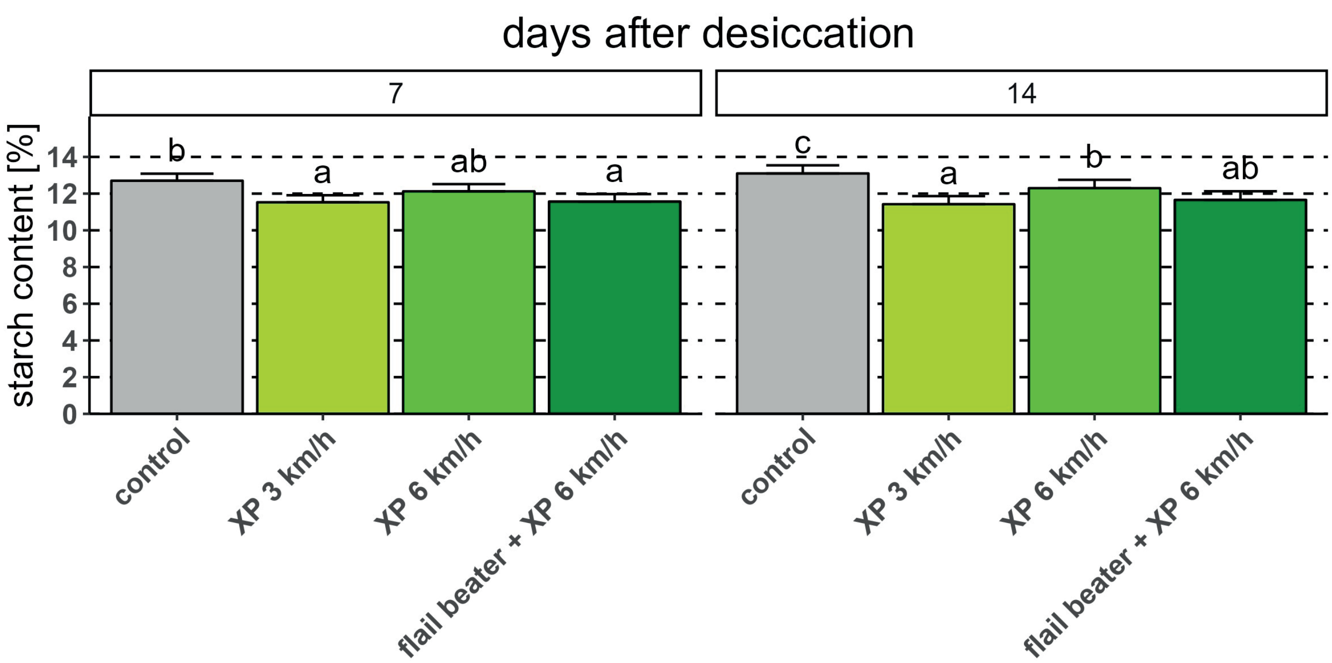

Fig. 5. Starch content [%] of potato tubers 7 and 14 days after desiccation at all sites (Bingen, Frankenthal and Mutterstadt), different letters indicate significant differences between desiccation programs, p ≤ 0.05, Tukey HSD test

efficacy were observed after 14 days. Consequently, the third hypothesis can be rejected. Nevertheless, a speed of 3 km h[1] and a working width of 3 m results in a theoretical area performance of less than 1 ha h^{-1}. Such a low area performance compared to the chemical desiccation leads to higher procedural costs.

The fourth hypothesis states that, desiccation on dry soil increases the internal potato tuber quality. The proportion of tubers with necrotized heel ends increased after electrophysical treatment, especially under dry soil conditions (Fig. 4). Therefore, the fourth hypothesis that the internal quality is not affected by the electrophysical system needs to be rejected. In general, under dry soil conditions, higher damage to plants is reported by electricity, although "dry" conditions are not precisely defined (Bauer et al., 2020). The fact that both, the severity and frequency of necrotized heel ends decreased with irrigation, indicates a lower level of the electricity in the tubers. However, the measured soil moisture content in the 0–12 cm soil layer showed only marginal differences between both irrigation scenarios (0 and 10 L m^{-2}, Table 5). The humidification of the uppermost layer is already sufficient to deconcentrate the electricity near the potato tubers.

Nevertheless, irrigation prior to electrophysical desiccation can be problematic. Due to the high weight of the applicator used (approx. 1,500 kg) and the generator used (approx. 800 kg) in combination with a tractor with narrow tires (necessary for ridge distance of 75 cm), irrigation should be reduced to a minimum to avoid soil structure problems. Despite the significant differences between treatments in the rating of necrotized heel ends, the electrophysical treatment rating of 1.4 was also at a level where marketing is not affected. Therefore, supplementary irrigation before application should only be considered in dry soil conditions. Unfortunately, no appropriate range of soil moisture content can be provided in the present study.

Reed (2009) concluded, if a suitable and reliable herbicide is available, it will always be preferred to the electrical control methods from a cost and effectiveness point of view. Nevertheless, the desire of the society for reduced chemical plant protection and the resulting political decisions require non-chemical alternatives. Electrophysical systems provide a residue-free approach, which can be used in herbicide-free farming. In the present study, we showed the suitability of this technology for the desiccation of early potatoes.

Conflicts of interest

The authors declare that they do not have any conflicts of interest.

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