Eur. Potato J. 11 (1968): 34–44

Relation between black spot and composition of the potato tuber

N. VERTREGT

Instituut voor Biologisch en Scheikundig Onderzoek van Landbouwgewassen (I.B.S.), Wageningen, The Netherlands

Accepted for publication: 9th October, 1967

Zusammenfassung, Résumé p. 43

Summary

The differences in black spot susceptibility between potato varieties and samples of different origin cannot be explained by differences in tyrosine content or phenoloxidase activity of the tubers.
Only 5–15% of the cells in a bruised part of the tissue are damaged and discoloured. Potato tubers, dissimilar in black spot susceptibility, have different potassium and dry matter contents. No differences exist in firmness and osmotic values. If the potassium supply is not limiting growth, the potassium content of potato tubers is about 650 meq. (25,4 g) per kg dry matter. Negligible black spot occurs in potatoes grown on silt soils in The Netherlands if the potassium content of the tubers exceeds 650 meq. per kg dry matter.

Introduction

Black spot in potato tubers is caused by oxidation of the aminoacid tyrosine via the red coloured compound dopachrome to the dark brown substance melanin, and may occur after bruising the tissue. Black spot can be reduced by potassium manuring (Oortwijn Botjes and Verhoeven, 1927). With increasing potassium application the dry matter content decreases and the potassium and tyrosine contents of the dry matter are increased (Jacob, 1959). Between different potato varieties there is a large variation in black spot susceptibility.
This article describes investigations into the relationships between the occurrence of black spot, the tyrosine content, the phenoloxidase activity and the firmness of the potato tuber. In addition, the possibility of reducing black spot by variety selection or fertilizer applications is considered.

Methods

Preparation of the sample
Samples of 25 potato tubers were peeled and longitudinally divided into two parts. After cutting in slices one part was dried at 75 °C for analysis of inorganic constituents. The other half was grated in a domestic sap centrifuge and the sap collected.

Determination of the tyrosine content (Udenfriend and Cooper, 1952)
Immediately after collecting 3 ml sap were mixed with 17 ml water and 5 ml 30% trichloroacetic-acid solution and centrifuged. Then 2 ml of the clear solution were mixed with 1 ml of a solution of 10 ml conc. HNO_3 and 30 mg $NaNO_3$ in 50 ml water and with 2 ml of a 0.1% solution of α-nitroso β-naphthol in alcohol and heated for 30 min at 60°C. After removal of the excess of nitrosonaphthol by extraction with 8 ml dichloroethane, the extinction was measured at 445 mμ.

Estimation of the phenoloxidase activity (Vertregt and Pannebakker, 1964, 1965)
The phenoloxidase activity was defined as the ratio between the content of tyrosine that is converted into dopachrome in 20 min at 25°C and the initial tyrosine content.

Determination of mineral constituents
The contents of the mineral constituents were determined by flame photometry and colorimetry. Nitrogen was determined by the Kjeldahl method.

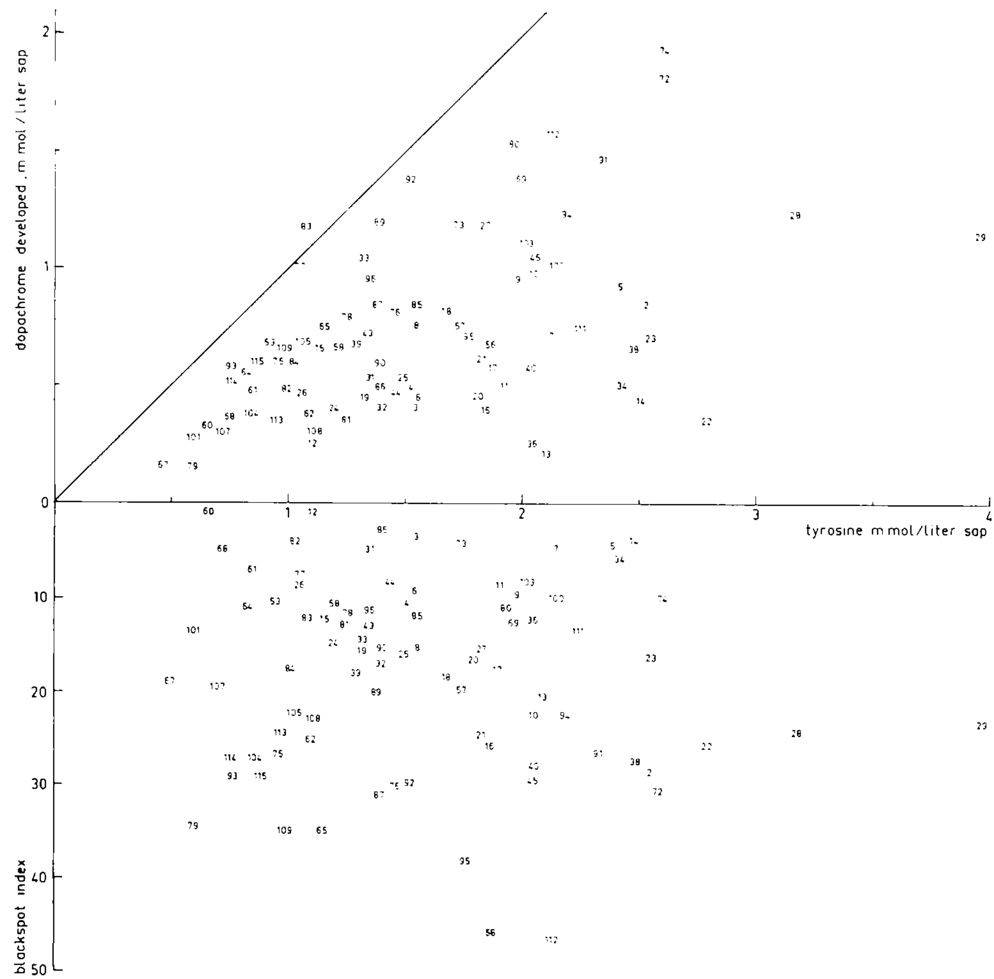
Estimation of black spot
Black spot was visually estimated three days after a standard bruising treatment in the peeled potatoes. The results are expressed as percentage of tubers showing black spot (Ophuis et al., 1958).
Comparing the different samples by a reflectometric procedure proved to be unreliable, as the dry matter content of the tissue influences the result to a considerable extent.

Experiments

The tyrosine content, the phenoloxidase activity and the black spot susceptibility of a number of potato varieties
About 100 potato varieties grown on one experimental field were analysed. The results are shown in Fig. 1. The numbers refer to the varieties listed in Table 1.
The highest possible amount of dopachrome formed appeared to depend on the tyrosine content of the sap. The phenoloxidase activity varied independently of the tyrosine content.
Severe black spot occasionally occurred at low tyrosine contents and low phenoloxidase activities as well as at high tyrosine contents and high phenoloxidase activities. Comparable results were obtained when analysing the same varieties originating from another experimental field. No relationship was found between emerging black spot and tyrosine content or phenoloxidase activity.

The tyrosine content during the growth of the potato tuber
Samples of *Bintje* and *Libertas* potatoes were periodically lifted. The yields, dry matter contents and tyrosine contents were determined. The results are given in Table 2.

Fig. 1. Tyrosine contents, dopachrome formation and black spot indices of tubers of about 100 potato seedlings and commercial varieties. Explanation of numbers in Table. 1



Dopachrome developed, mmol litre – *gebildetes Dopachrom, mmol Liter Saft – dopachrome développé, mmol litre de jus*
Blackspot index – *Blaufleckigkeitsindex – index de tache noire*
Tyrosine, mmol litre sap – *Tyrosin, mmol Liter Saft – tyrosine, mmol litre de jus*

Abb. 1. Tyrosingehalt, Bildung von Dopachrom und Blaufleckigkeitsindex für Knollen von ungefähr 100 Kartoffelstämmen und Handelssorten. Erklärung der Zahlen siehe Tabelle 1.
Fig. 1. Teneurs en tyrosine, formation de dopachrome et index de taches noires de tubercules provenant de quelque 100 plantules de Pomme de terre et variétés commerciales. Explication des nombres au Tableau 1.

Table 1. Names of seedlings and commercial varieties relating to Fig. 1

2 Eersteling	24 Ari	61 Dalco	87 Rode Star
3 Civa	25 Sientje	62 Rademakers 50-2625	89 Pimpernel
4 Barima	26 Avenir	64 Realta	90 Record
5 Doré	27 Zingstra 51-676	65 Plat 52-9	91 Goliath
6 Saskia	28 Urgenta	67 C.B. 52-51-17	92 Prudal
7 Dolfing 50-04	29 Désirée	68 Pandora	93 Froma
8 P.G.V. 55-121	31 Spartaan	69 Bevelander	94 Ultimus
9 Primura	32 Radosa	72 Noordeling	95 Engelum I 2749
10 Sirtema	33 Patrones	73 Surprise	96 Herkol
11 Asoka	34 C.B. 52-105-9	74 Amelio	100 Dijkhuis 51-755
12 Ostara	36 M.G. 54-92	75 Amaryl	101 Mentor
13 Béa	38 Minkes	76 Mansholt 52-12	103 Mulder H 24
14 Humalda	39 Zeeland 52-37	77 CIV. 54-2391	104 Voran
15 Crébas	40 Arran Banner	78 Libertas	105 Enting 55-902
16 Ideaal	43 P.W. Loman 53-89	79 Plato	107 Karna 54-563
17 Fennema 55-31	44 Zingstra 1-3-729	80 IJsselster	108 Atleet
18 Plat 52-11	45 Pionier	81 Irene	109 Mansholt 53-124
19 Bintje	53 Eigenheimer	82 Eskes-Hofstra 53-97	111 Doornbos 52-114
20 Climax	56 Prefect	83 Burmania	112 Loman 53-123
21 Allerfrüheste Gelbe	57 Meerlander	84 Woudster	113 Schildt 5 B 44
22 Dijkhuis 52-211	58 Kwinta	85 Furore	114 Ambassadeur
23 Engelum G 495	60 Extase	86 Geertsema	115 Maritta

Tabelle 1. Namen der Stämme und Handelssorten mit Bezug auf Abb. 1
Tableau 1. Nom des plantules et variétés commerciales mentionnées dans la Fig. 1

Table 2. The tyrosine content during the tuber growth of two varieties

Date of lifting[1]	*Tyrosine content mmol/litre of sap*[2]		*Yield (kg dry matter/ha)*[3]		*Dry matter content*[4]	
	Bintje	*Libertas*	*Bintje*	*Libertas*	*Bintje*	*Libertas*
10- 7-1962	0.28	0.60	3,300	2,000	19.6	19.3
24- 7-1962	0.38	0.69	5,100	4,000	20.1	22.0
7- 8-1962	0.60	0.80	7,000	5,200	24.8	26.0
21- 8-1962	0.74	0.99	7,700	7,100	22.8	25.9
4- 9-1962	0.87	1.03	8,800	8,400	23.1	26.3
18- 9-1962	1.14	0.95	8,400	8,500	21.4	25.5
30-10-1962	1.06	1.18	8,500	10,000	26.1	25.1

[1] *Erntedatum – date d'arrachage*
[2] *Tyrosingehalt (mmol Liter Saft) – teneur en tyrosine (mmol litre de jus)*
[3] *Ertrag (kg Trockensubstanz ha) – production (kg de matière sèche ha)*
[4] *Trockensubstanzgehalt – teneur en matière sèche*

Tabelle 2. Der Tyrosingehalt während des Knollenwachstums bei zwei Sorten
Tableau 2. Teneur en tyrosine au cours de la croissance de deux variétés

The tyrosine content increased during the growth of the tubers. At the end of the growing period the tyrosine content assumed a constant value.

The effect of tissue firmness on black spot

It appears from the results given above that differences in the black spot susceptibility of potato varieties cannot be explained by differences in tyrosine content or phenoloxidase activity.

They are probably caused by differences in resistance to damage after bruising.

Aliquot parts of a sample of *Libertas* potatoes were bruised during 0, 1, 3 and 10 min, respectively, in an electric potato washer. The potatoes were analysed after a 3-day storage period. The results are given in Table 3.

With increasing bruising time the tyrosine content in the sap and dopachrome formation decreased and black spot increased. The alterations in tyrosine concentration were relatively small. This agrees with the observation that only a small part of the cells, evenly distributed over the bluish tissue, were discoloured. The percentage discoloured cells corresponds with the percentage diminution of the total tyrosine content in the tissue, suggesting that tyrosine conversion was complete in the discoloured damaged cells, whereas the tyrosine content of the undamaged undiscoloured cells had not changed. Since severely discoloured tissue contains only a small percentage, 5–15 %, of damaged cells, it will be difficult to obtain conclusive evidence on the degree of discolouration from analysis of the whole tissue.

Two samples of *Bintje* potatoes differing in back spot susceptibility, were analysed. The results are given in Table 4.

The samples differed appreciably in potassium and dry matter contents, and, on a lower level, in chloride content, but only small differences in freezing-point depression, osmotic pressure, diffusion pressure deficit and firmness of the tissue were found. Apparently, the susceptibility to bruising cannot be estimated by measuring the tissue firmness, nor by measuring the above mentioned osmotic values.

Table 3. Changes in the tyrosine content of potato tubers after different bruising treatments

	0 min	*1 min*	*3 min*	*10 min*
Tyrosine content[1] (mmol/litre of sap)	1.76	1.70	1.62	1.51
Dopachrome formed[2] (mmol/litre of sap)	1.13	1.11	1.08	0.96
Reflectance (crushed tissue)[3]	100	86.5	76.5	65.6

[1] *Tyrosingehalt (mmol/Liter Saft) – teneur en tyrosine (mmol/litre de jus)*
[2] *Gebildetes Dopachrom – dopachrome formé*
[3] *Reflexionsphotometerwert (gequetschtes Gewebe) – pouvoir de réflexion (tissu broyé)*

Tabelle 3. Änderung im Tyrosingehalt in Kartoffelknollen nach verschiedenen Quetschungsbehandlungen
Tableau 3. Modifications de la teneur en tyrosine de tubercules de Pomme de terre après l'action plus ou moins prolongée de chocs

The composition of potato tubers

Greenhouse experiments. A number of greenhouse experiments have shown that the Na-, Ca-, Mg- and SO_4-contents of potato tubers can only to a moderate extent be varied by fertilizer application. The K-, N- and Cl-contents can, on the contrary, be considerably altered.

A single tuber of the variety *Alpha* was planted in each of a number of buckets filled

Table 4. The composition of two samples of *Bintje* potatoes with different black spot indices

	Sample[1] *I*	*Sample II*
K, meq./kg d.m.[2]	328	600
Ratio K in bud end/K in stem end[3]	1.39	1.15
N, meq./kg d.m.	1150	1190
Cl, meq./kg d.m.	85	60
% d.m.	25.0	20.4
Firmness[4]	33	29
Osmotic pressure (mol)[5]	0.545	0.535
Diffusion pressure deficit (mol)[6]	0.260	0.265
Freezing point (°C)[7]	–0.517	–0.520
Black spot index[8]	47	8

[1] *Muster – échantillon*
[2] *Kalium, meq./kg Trockensubstanz – potassium, méq./kg matière sèche*
[3] *Verhältnis von K am Kronenende zu K am Nabelende – rapport K à l'extrémité du bourgeon/K à l'extrémité de la tige*
[4] *Festigkeit des Fleisches – fermeté*
[5] *Osmotischer Druck (mol) – pression osmotique (mol)*
[6] *Diffusionsdruckdefizit (mol) – déficit de pression de diffusion (mol)*
[7] *Gefrierpunkt (°C) – point de congélation (°C)*
[8] *Blaufleckigkeitsindex – index de tache noire*

Tabelle 4. Die Zusammensetzung von zwei Kartoffelmustern der Sorte Bintje mit verschiedenen Blaufleckigkeitindizes

Tableau 4. Composition de deux échantillons de pommes de terre Bintje avec différents index de taches noires

Table 5. Mineral nutrition per plant (greenhouse experiment)

$CaCO_3$:	600 meq.	B:	3 mg
MgO:	200 meq.	Co:	0.1 mg
$MgSO_4$:	100 meg.	Cu:	10 mg
$Ca(H_2PO_4)_2$:	50 meq.	Mn:	100 mg
NO_3^-:	125, 250 or 375 meq.	Mo:	2 mg
K^+:	80, 160 or 240 meq.	Fe:	200 mg
		Zn:	10 mg

Excess NO_3^- applied as[1] $Ca(NO_3)_2$
Excess K^+ applied as K_2SO_4

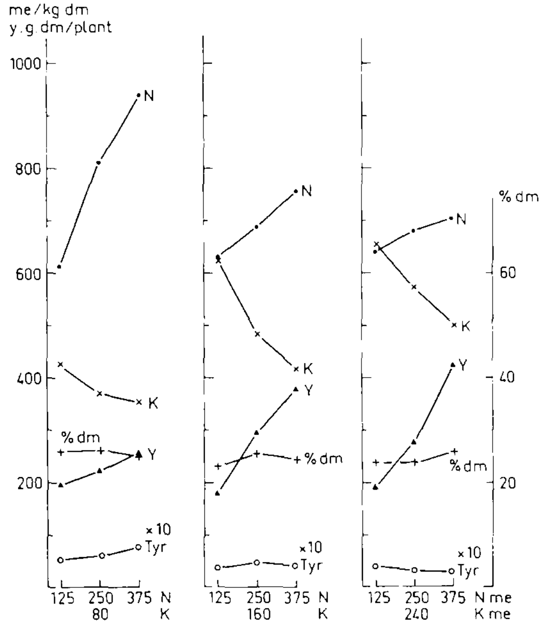
[1] *Überschuss an NO_3^- zugeführt als – excès NO_3^- appliqué sous forme de*

Tabelle 5. Mineralische Nährstoffe pro Pflanze (Glashausversuch)
Tableau 5. Nutrition minérale par plante (expérience en serre)

with 14 litres of poor sandy soil, in a greenhouse, fertilizer of the composition given in Table 5 being applied in two parts. Half of it was applied at planting and the rest 2 weeks after emergence. Eight leaves had developed by this time. The results of the experiment are shown in Fig. 2.

At the beginning of flowering the plants treated with 250 meq. NO_3 + 80 meq. K and 375 meq. NO_3 + 80 meq. K showed potassium deficiency symptoms in the foliage. A higher nitrogen dose resulted in a higher nitrogen content of the tubers, a higher yield and a decrease in potassium content. If more potassium was applied at the same nitrogen level, the yield increased and the nitrogen content decreased, but the yield and the potassium content dit not increase beyond the point where a potassium content in the tuber of 650 meq./kg dry matter was reached. At the higher nitrogen levels the plants were more or less potassium deficient. The nitrogen content did not decrease below 650 meq./kg dry matter. Under optimal conditions of potassium supply the potassium content of potato tubers was 650 meq./kg dry matter.

Fig. 2. The yield and the potassium, nitrogen, dry matter and tyrosine contents of tubers of *Alpha* potatoes collected from a greenhouse experiment.

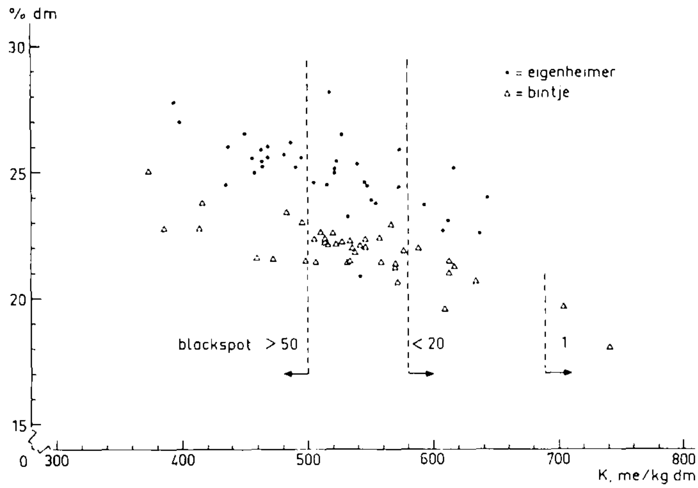


Meq. kg d.m. – *meq. kg Trockensubstanz – méq. kg matière sèche*
Y, g d.m. plant – *Ertrag, g Trockensubstanz pro Pflanze – rendement, g matière sèche plante*

Abb. 2. Ertrag und Kalium-, Stickstoff-, Trockensubstanz- und Tyrosingehalt bei Kartoffelknollen der Sorte Alpha aus einem Glashausversuch.

Fig. 2. Rendement et teneurs en potassium, azote, matière sèche et tyrosine de tubercules de Pomme de terre Alpha récoltés dans une expérience en serre.

Fig. 3. Potassium and dry matter contents and black spot susceptibility of *Bintje* and *Eigenheimer* potatoes collected from different fields in the south-western silt-soil region of The Netherlands.



% d.m. – % *Trockensubstanz* – % *matière sèche*
K, meq./kg d.m. – *Kalium, meq./kg Trockensubstanz* – *potassium, méq./kg matière sèche*
Blackspot – *Blaufleckigkeit* – *tache noire*

Abb. 3. Kalium- und Trockensubstanzgehalt sowie Neigung zur Blaufleckigkeit bei Kartoffeln der Sorten Bintje und Eigenheimer, die aus verschiedenen Feldern der südwestlichen Lehmbodenregion der Niederlande stammen.

Fig. 3. Teneurs en potassium et matière sèche et susceptibilité aux taches noires de pommes de terre Bintje et Eigenheimer récoltées dans différentes champs dans la région de sol argileux du sud-ouest de la Hollande

Field experiments. The dry matter content, potassium content and black spot susceptibility were determined on a number of potato samples cultivated on silt soils in the south-western part of The Netherlands. The results are shown in Fig. 3.

Black spot was generally under 20% if the potatoes had potassium contents over 580 meq./kg d.m. Black spot was over 50% at potassium contents under 500 meq./kg d.m. These limits were valid for both *Bintje* and *Eigenheimer*, although these varieties differed considerably in dry matter content. Comparable results on the relation between black spot and potassium content were published by Oortwijn Botjes and Verhoeven (1927) and Ophuis et al. (1958).

A similar relation between potassium content, dry matter content and black spot was found when the potassium content was expressed in fresh weight. This is because differences in dry matter content are largely exceeded by differences in potassium content.

There were comparatively few (12 out of 79) samples with potassium contents over 600 meq./kg d.m., which is the lower limit of optimal growth, as appeared from the

Table 6. The effect of potassium manuring on the potassium content of potatoes grown on silt soils in The Netherlands

K-manuring[1] *(kg/ha)*	*N-manuring* *(kg/ha)*	*Tuber yield*[2] *(kg d.m./ha)*	*K-content*[3] *(meq./kg d.m.)*	*K in yield*[4] *(kg/ha)*	*N-content* *(meq./kg d.m.)*	*N in yield* *(kg/ha)*
0	45	7800	368	115	778	85
140	45	8660	432	150	792	96
280	45	8960	466	167	800	100
0	300	10100	399	161	1271	180
140	300	10000	455	182	1371	192
280	300	10400	471	196	1321	192

[1] *K-Düngung – apport potassique*
[2] *Knollenertrag (kg Trockensubstanz/ha) – production en tubercules (kg matière sèche/ha)*
[3] *K-Gehalt – quantité de potassium*
[4] *K im Ertrag – exportation de potasse*

Tabelle 6. Einfluss von Kaliumdüngung auf den Kaliumgehalt bei Kartoffeln aus Lehmböden der Niederlande

Tableau 6. Effet de la fumure potassique sur la teneur en potassium de pomme de terre récoltées sur sols argileux de Hollande

greenhouse experiment described above, though two samples contained over 700 meq./kg d.m., associated with a black spot index under 1. In view of this critical value of 600 meq./kg d.m. it appeared to be difficult to supply sufficient potassium with the fertilizer to the tubers grown on these soils, as is illustrated by the results of an experiment shown in Table 6. In the field experiment described in Table 6 there was only a small influence of nitrogen manuring on potassium content, in contrast with the results of the greenhouse experiment.

Conclusion

The occurrence of black spot in potatoes does not depend on the tissue content of the parent substance of the colouring compound, the aminoacid tyrosine. It is questionable whether the cause of black spot susceptibility may be assessed by chemical analysis, since only a small part of the tissue cells are affected.
Black spot susceptibility disappears with sufficient potassium in the tissue. Its prevention requires potassium contents of 600–650 meq. potassium per kg dry matter.

Acknowledgments

Thanks are due to Miss E. G. Pannebakker for analytical help and to Ir. J. C. Hesen, G. Hulstein and C. P. Meijers, Instituut voor Bewaring en Verwerking van Landbouwprodukten (I.B.V.L.), Wageningen for carrying out the black spot estimations. Financial aid was obtained from the I.B.V.L.

Zusammenfassung

Beziehung zwischen Blaufleckigkeit und Zusammensetzung der Kartoffelknolle

Die Unterschiede in der Empfindlichkeit für Blaufleckigkeit zwischen Kartoffelsorten und Mustern verschiedener Herkunft können nicht durch die Unterschiede im Tyrosingehalt oder in der Phenoloxydase-Aktivität der Knollen erklärt werden (Abb. 1, Tabelle 1). Das Fehlen einer Korrelation mit dem Tyrosingehalt und die Tatsache, dass die Änderung dieses Gehalts während der Reifezeit, verglichen mit den Unterschieden zwischen den Sorten, gering ist, weisen darauf hin, dass die Erntezeit, was ihren Einfluss auf den Tyrosingehalt betrifft, das Vorkommen von Blaufleckigkeit nich beeinflusst (Tabelle 2).
In einer beschädigten Zelle wird das Tyrosin vollständig in Melanin umgewandelt. Nur 5–15 % der Zellen, im gequetschten Teil des Gewebes gleichmässig verteilt, werden verfärbt.
Kartoffelknollen, die in ihrer Empfindlichkeit für Blaufleckigkeit ungleich sind, weisen unterschiedliche Kalium- und Trockensubstanzgehalte auf. Keine Unterschiede bestehen in der Festigkeit des Fleiches und den osmotischen Werten (Tabelle 4).
Wenn die Kaliumgabe das Wachstum nicht beschränkt, beträgt der Kaliumgehalt der Kartoffelknollen ungefähr 650 meq. (25,4 g) pro kg Trockensubstanz (Tabelle 5, Abb. 2). Auf den Tonböden im Südwesten der Niederlande ist es schwierig, Kartoffeln mit einem Kaliumgehalt von über 650 meq. pro kg Trockensubstanz zu erzeugen (Tabelle 6).
Nur geringfügige Blaufleckigkeit kommt bei Kartoffeln aus diesen Böden vor, wenn der Kaliumgehalt 650 meq. pro kg Trockensubstanz übersteigt (Abb. 5).

Résumé

Relation entre la maladie des taches noires et la composition du tubercule de Pomme de terre

Les différences dans la susceptibilité aux taches noires entre variétés de Pomme de terre et entre échantillons de diverses origines ne peuvent s'expliquer par des différences de teneur en tyrosine ou d'activité de la phénoloxydase des tubercules (Fig. 1, Tableau 1). Ce manque de corrélation avec la teneur en tyrosine et le fait que cette teneur est faible pendant la maturation comparée aux différences variétales suggèrent que le moment de l'arrachage, pour autant qu'il ait une action sur la tyrosine, n'influence pas l'incidence des taches noires (Tableau 2).
Dans une cellule endommagée la tyrosine est complètement convertie en mélanine. Seulement 5–15 % des cellules, réparties uniformément sur la partie contusionnée du tissu, sont décolorées.
Des tubercules de Pomme de terre, différents dans leur susceptibilité aux taches noires, ont des teneurs différentes en potassium et matière sèche. On n'aperçoit aucune différence dans la fermeté et valeur osmotique (Tableau 4).
Si un apport complémentaire de potassium ne limite pas la croissance, la teneur des tubercules en cet élément est d'environ 650 méq. (25,4 g) par kg de matière sèche (Tableau 5, Fig. 2). Dans les sols argileux du sud-ouest de la Hollande il est difficile de récolter des pommes de terre avec des teneurs en potassium supérieures à 650 meq. par kg de matière sèche (Tableau 6).
L'apparition de taches noires est négligeable dans les tubercules récoltés sur ces sols si la teneur en potassium excède 650 meq. par kg de matière sèche (Fig. 3).

References

Jacob, W. C., 1959. Studies on internal black spot in potatoes. *Mem. Cornell Univ. agric. Exp. Stn* 368.

Lerner, A. B. and Fitzpatrick, Th. B., 1950. Biochemistry of melanin formation. *Physiol. Rev.* 30: 91–125.

Oortwijn Botjes, J. and Verhoeven, W. B. L., 1927. Het blauw worden van aardappelen. *Tijdschr. PlZiekt.* 33: 57–96.

Ophuis, B. G., Hesen, J. C. and Kroesbergen, E., 1958. The influence of temperature during handling on the occurrence of blue discolorations inside potato tubers. *Eur. Potato J.* 1 (3): 48–65.

Udenfriend, S. and Cooper, L., 1952. The chemical estimation of tyrosine and tyramine. *J. biol. Chem.* 196: 227.

Vertregt, N. and Pannebakker, E. G., 1964. Determination of the discolouration of raw potatoes. *Jaarb. Inst. biol. scheik. Onderz. Landb.Gewass.* pp. 165–166.

Vertregt, N. and Pannebakker, E. G., 1965. Dopachrome formation in potatoes. *Jaarb. Inst. biol. scheik. Onderz. LandbGewass.*, pp. 113–116.