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Use of 2-aminobutane as a fumigant for control of gangrene, skin spot and silver scurf diseases of potato tubers

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Zusammenfassung, Résumé p. 123

Summary

Fumigation of tubers with 2-aminobutane (sec-butylamine) gas at a dosage of 200 mg/kg in simply made fumigation chambers gave very good control of the diseases gangrene (caused by *Phoma exigua* var. *foveata*) and skin spot (*Oospora pustulans*) if treatment was done within 14 days of harvesting. Some control of silver scurf disease (*Helminthosporium solani*) was also obtained, but results were always poorer than with gangrene or skin spot. Fumigation did not control tuber blight (*Phytophthora infestans*), dry rot (*Fusarium solani* var. *caeruleum*) and did not kill the sclerotia of *Rhizoctonia solani*.

Since chemical analysis of treated peeled and boiled tubers, and crisps, granules and flakes made from treated tubers showed that they contained substantial residues of 2-aminobutane, the treatment can only be used on seed tubers. There were no significant residues in crops grown from treated tubers.

Introduction

The potato tuber can be attacked by many fungal and bacterial diseases during storage. At present one of the most troublesome tuber diseases in Scotland is gangrene, which is a rot of the tuber flesh caused by *Phoma exigua* var. *foveata*. Skin spot, caused by *Oospora pustulans*, is also important on certain susceptible varieties. It appears as small pustules on the tuber surface and more importantly, eyes may be killed, thus affecting sprouting. Silver scurf, caused by *Helminthosporium solani*, is a skin disease of less importance but it disfigures tubers and causes flaccidity by accelerating water loss through damaged skin.

Many attempts have been made to control these diseases chemically but until recently, the only successful method was dipping in a solution of an organo-mercury compound. This treatment has several disadvantages such as the toxic hazard associated with mercurials as well as the problem of drying tubers and has made only limited impact on the seed trade. However, the situation changed with the introduction of the systemic benzimidazole fungicides as dust and dip treatments (Hide et al., 1969) and fumigation of tubers with 2-aminobutane (sec-butylamine) (Graham and Hamilton, 1970). Graham and Hamilton (1970) drew attention to the basically simple idea of introducing gas into bulks of tubers, and outlined the fumigation process briefly. They gave some data on the degree of control of skin spot and gangrene both when

small quantities of tubers were fumigated at different dosages and when bulk fumigations were done in a specially designed chamber holding 5000 kg of tubers.

This paper describes the process of fumigation in more detail, briefly outlines the construction of a special cylindrical fumigation chamber and two chambers for bulk fumigations and discusses results of fumigating bulks of tubers at different dosages at various times after lifting to determine the degree of disease control. Residue levels in treated and processed tubers are also given.

Some properties of 2-aminobutane

2-Aminobutane is a colourless or pale amber liquid, boiling point 63 °C, and thus easily vaporised. It is inflammable (flash point −19.5 °C) and the lower explosive limit in air is 21–25 g/kg, but such concentrations are never reached when the chemical is used as a potato fumigant. 2-Aminobutane is an organic base which, having an asymmetric carbon, exists as optical isomers, and the commercially available products are racemic mixtures. The (−) enantiomorpu is considerably more biologically active than the (+), both in preventing spore germination and in inhibiting mycelial growth (Eckert et al., 1970). 2-Aminobutane is stable, but corrosive to tin, aluminium, copper and its alloys and some steels.

It is a moderately toxic substance (rat oral LD_{50}, 380 mg/kg) and experience has shown that hazards relating to application are primarily due to its alkalinity. Like ammonia, these effects are minimised by dilution (it is miscible with water) or as the basicity is neutralised (Anon., 1966). Certain precautions need to be taken when using this substance and an official 'Code of practice' for safe use of the chemical on potatoes has been published, which may be obtained from the authors.

The process of fumigation and chamber construction

The first small-scale fumigations with 2-aminobutane were done in a steel fumigation chamber designed for work with other gases. These tests showed that absorption of gaseous 2-aminobutane by tubers was too rapid for the ct (concentration × time) product method of expressing treatment to be practicable, and so the ratio weight of fumigant to weight of potatoes treated, expressed in mg/kg, was used instead. It was also found that rapid stirring or better still some system of forced air recirculation was necessary to obtain good distribution of the gas.

Because good disease control was achieved in the early fumigations at dosage rates of around 200 mg/kg a prototype fumigation chamber holding 5000 kg of potatoes was built to study the process of fumigation with larger bulks of tubers. The design was basically a gas-tight wooden box reinforced with a steel frame (Fig. 1). It was 3 m long, 2 m wide and 2.5 m high with double doors at one end, the potatoes being held in position by removable bulkheads. The floor was made of boards 25 cm in width with carefully adjusted spaces between them to provide an even air flow up through the bulk of potatoes. Between the floor holding the potatoes and the bottom of the

Fig. 1. Five-tonne box fumigation chamber, with fan, vaporiser and recirculation piping system.

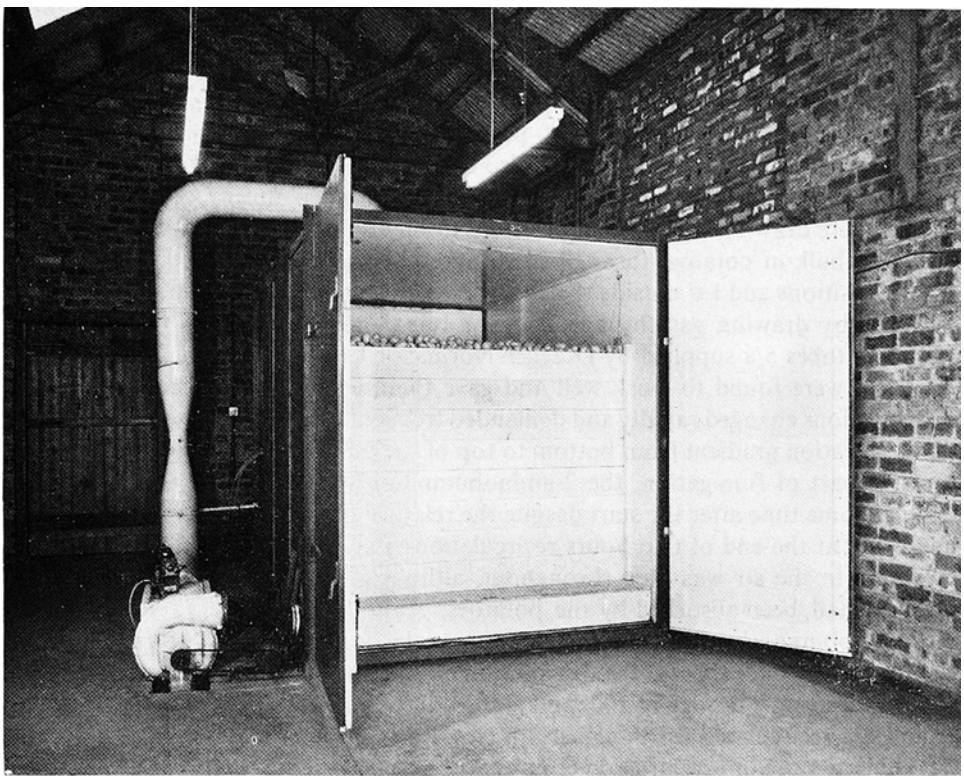

Abb. 1. Gaskammer, Kapazität fünf Tonnen, eingerichtet mit Gebläse, Verdampfer und für Gas-Innenkreislauf.
Fig. 1. Chambre de fumigation, capacité cinq tonnes avec ventilateur et vaporisateur, système de récirculation.

chamber there was a 20-cm high air space. All the internal surfaces were coated with a chemical-resistant paint. The air and gas was blown by a centrifugal fan via a box duct containing deflector baffles into the under-floor space, up through the potatoes, out through 0.3 m diameter trunking in the roof of the chamber and returned to the chamber via a vaporiser and the fan. The vaporiser consisted of a tank with a hot water jacket fitted with an immersion heater capable of raising the temperature to around the boiling point of 2-aminobutane, which was run into it through a small pipe in the lid. The vaporiser was built to ensure that the fumigant could be vaporised at any specified rate, otherwise vapourisation would have been dependent solely on the effect of the air stream. When the chamber was filled with potatoes, the height of the potetoes from bottom to top was about 1.5 m. Further details about the construction of this chamber can be obtained from the authors.

Because 2-aminobutane can be very rapidly absorbed by potatoes, most of the fumigant could be absorbed by the lower layers, resulting in inadequate distribution throughout the bulk. To overcome this difficulty it was decided to use a reasonably fast air flow of 28 m^3 per minute to try to blow the gas up through the bulk to the top before it was all absorbed. This flow of 5.6 m^3 min^{-1} t^{-1} was about 5 times the rate recommended for ventilation of potatoes (Anon., 1960). At first various rates of application of 2-aminobutane were also tried to see how this affected distribution.

Free gaseous 2-aminobutane measurements were taken during the fumigations. Samples were drawn from different positions inside the fumigation chamber and from within the bulk of potatoes through small bore polythene tubes which terminated at various positions and led outside the chamber. The 2-aminobutane concentration was measured by drawing gas through detector tubes designed for use with ammonia (ammonia tubes 5/a supplied by Draeger-Normalair Ltd) with a bellows attachment. The tubes were found to work well and gave the quick readings necessary because concentrations changed rapidly and demanded frequent measurements at many points. A concentration gradient from bottom to top of the bulk was always observed during the early part of fumigation, the 2-aminobutane only reaching the upper layers of potatoes some time after the start despite the relatively high air flow. However, it was found that at the end of two hours recirculation after fumigant was added, the concentration in the air was even throughout, although very low, because most of the fumigant had been absorbed by the potatoes. Although there was rapid absorption of 2-aminobutane by the potatoes, residue analyses of tubers taken from various positions in the bulk showed the distribution of 2-aminobutane to be reasonably even throughout using a dosage of 200 mg/kg, introduced in 30–40 min and the mixture of air and gas recirculated for a further 2 h (see Table 1).

To obtain more information on the physical process of fumigation, particularly the 2-aminobutane distribution on potatoes throughout a high bulk of tubers, a special chamber was made for this work. A steel cylinder of 0.1 m^2 cross sectional area and 3 m high was constructed, having clip-fastened gas-tight ports at the top, middle and bottom to allow easy access to the potatoes inside. It was fitted with a fan, vaporiser, flow meter and the necessary piping to complete a closed recirculatory system (Fig. 2). Samples of potatoes could be withdrawn within a minute while the fan and the fumigant application were stopped, so that samples could be taken both during and after the addition of the fumigant. More samples could also be taken at different stages of air recirculation. The cylinder held 175 kg of potatoes, compared with 5000 kg in the larger chamber. Thus the effects of different rates of application of fumigant, different air flow rates, and the best length of time for recirculation of air after all the fumigant had been introduced were studied realistically, but with relatively small amounts of potatoes. Much information was obtained, such as the fact that most of the 2-aminobutane was absorbed by the potatoes near the bottom of the cylinder during application of the fumigant. Much of this was desorbed then reabsorbed by the tubers above during the recirculation period so that the 2-aminobutane moved upwards through the column. However, for reasons which were not clear, these scaled-down

Fig. 2. Cylindrical fumigation chamber. Bottom port is open.

Abb. 2. Zylindrische Gaskammer. Die unterste Luke ist offen.
Fig. 2. Chambre de fumigation cylindrique. L'hublot le plus bas est ouvert.

treatments did not achieve such good distribution as in the 5-tonne treatments and the information obtained did not suggest improvements in the dosage and air flow or the recirculation time for 5-tonne fumigations, which had already been found empirically. The experiments did show, however, that it was possible to move 2-aminobutane from the bottom to the top of a column of potatoes 3 m high and that the absorption, desorption and reabsorption process took place irrespective of whether soil adhering to tubers was dry or moist.

Another fumigation chamber has been designed for the fumigation of boxed potatoes, based on the same principle as the 5-tonne prototype. It was constructed for fumigation of virus-tested stem cutting stocks of potatoes raised by the Department of Agriculture and Fisheries for Scotland. The fumigant-air mixture is blown up through 2 parallel ducts on which the boxes of potatoes are resting, out through

trunking in the roof, back through a fan and vaporiser before being recirculated through the boxes. This chamber was built with the help of the National Institute of Agricultural Engineering (Scottish Station). Details of construction may be obtained from the Director, NIAE, Scottish Field Station, Penicuik, Midlothian, Scotland.

Residues of 2-aminobutane in treated tubers

Residues of 2-aminobutane in relation to the distribution of gas in bulks of tubers

By analysis of 2-aminobutane residues in tubers it was possible to determine the evenness of 2-aminobutane distribution throughout bulks of tubers. The potatoes were analysed by the gas chromatographic method of Day et al. (1968), but omitting the use of the carbon tetrachloride wash. Considerable variation was found in the residues of individual potatoes and even of adjacent tubers. This was almost certainly due to the condition of the skin since higher residues were found in immature tubers

Table 1. Residues of 2-aminobutane in potatoes fumigated within 2 days of lifting in the 5-tonne prototype fumigation chamber.

Cultivar[1]	Dose[2] (mg/kg)	Sample position in chamber[3]	Residue[4] (mg/kg)
Redskin 1	200	top[5]	194
		bottom[6]	182
Majestic 1	200	top	103
		bottom	113
Redskin 2	200	top	92
		bottom	160
King Edward 1	200	top	92
		bottom	90
King Edward 2	50	top	12
		middle[7]	39
		bottom	32
Redskin 3	50	top	2
		middle	11
		bottom	23

[1] *Sorte – Variété*
[2] *Dosis – Dose*
[3] *Lage des Musters in der Kammer – Position de l'échantillon prélevé dans la chambre*
[4] *Rückstand – Résidu*
[5] *Oben – Sommet*
[6] *Unten – Base*
[7] *Mitte – Milieu*

Tabelle 1. Rückstände von 2-Aminobutan in Kartoffeln, die innerhalb von 2 Tagen nach der Ernte in der 5-Tonnen-Prototype-Gaskammer begast wurden.
Tableau 1. Résidu de 2-aminobutane dans des pommes de terre traitées par fumigation dans les 2 jours qui suivent l'arrachage, dans un prototype de chambre à fumigation de 5 tonnes.

and in others where the skin was damaged. To reduce this variation, sound quarters from each of four tubers of fairly uniform seed size were taken for each analysis.

Typical residues in potatoes fumigated in the 5-tonne fumigation chamber where the dose was introduced in 30–40 min and then recirculation done for a further 2 h are shown in Table 1. As mentioned above, good distribution with a dosage of 200 mg/kg was achieved, but at 50 mg/kg dosage most of the residue was confined to the lower tubers indicating this dose to be insufficient for equal distribution to occur.

There was some reduction in residue when potatoes were stored under well ventilated conditions, such as in open trays. However, the variation between individual tubers made it difficult to establish this with certainty, and substantial residues of 2-aminobutane were still present after many months storage.

Residues of 2-aminobutane remaining after peeling, cooking and processing

Residues of 2-aminobutane were determined to see if fumigation could be applied to ware (table) potatoes, since it was possible that residues might not remain after peeling, cooking or processing. Tubers given a dose of 200 mg/kg were used in these experiments.

Peeling

The fumigated potatoes were peeled with an ordinary hand peeler which removed

Table 2. Residues of 2-aminobutane in the peel and flesh of fumigated potatoes.

Cultivar[1]	Residue in flesh[2] (mg/kg)	Residue in peel[3] (mg/kg)	Calculated residue in whole tuber[4] (mg/kg)	Residue removed by peeling[5] (%)
Redskin 1	8	193	28	73
Majestic	13	294	48	75
Redskin 2	24	374	53	58
King Edward 1	28	508	66	60
King Edward 2	63	688	130	57
Redskin 3	16	365	45	66
King Edward 3	33	244	55	44
King Edward 4	22	192	40	50
Pentland Crown 1	24	471	62	64
Pentland Crown 2	23	420	56	70

[1] *Sorte – Variété*
[2] *Rückstand im Fleisch – Résidu dans la chair*
[3] *Rückstand in der Schale – Résidu dans la peau*
[4] *Berechneter Rückstand in der ganzen Knolle – Résidu calculé dans le tubercule entier*
[5] *Rückstand, entfernt durch das Schälen – Résidu éliminé par l'épluchage*

Tabelle 2. Rückstände von 2-Aminobutan in der Schale und im Fleisch der begasten Kartoffeln.
Tableau 2. Résidu de 2-aminobutane dans la peau et la chair de tubercules soumis à la fumigation.

about 10–12% by weight of the tuber. The peelings and flesh were analysed separately. The results shown in Table 2 indicate that about 60–70% of the residue was in the peel, so that significant amounts had passed into the flesh.

Cooking – boiling

Fumigated potatoes were peeled and halved and one half cooked by boiling in salted water and analysed. The other half was analysed to determine the residue level before cooking and in some cases the water in which the potatoes were cooked was also analysed. The results shown in Table 3 indicate that about 35% of the 2-aminobutane was lost during boiling. Some of this could be found in the cooking water. No allowance was made for the loss in weight of the potatoes during cooking, which can be as much as 30%.

Cooking – crisping

Fumigated potatoes were peeled and crisped under conditions used by commercial

Table 3. Effect of cooking on residues of 2-aminobutane in fumigated potatoes.

Treatment and cultivar[1]	Residue in uncooked flesh[2] (mg/kg)	Residue in cooked flesh[3] (mg/kg)	Residue removed by cooking[4] (%)
Cooking by boiling[5]			
Redskin 1	18.8	10.3	45
King Edward 1	42.4	26.1	39
Majestic 1	53.0	37.0	30
Majestic 2	20.0	15.3	24
King Edward	10.0	5.9	41
Pentland Crown 1	24.0	15.1	37
Pentland Crown 2	14.1	8.4	40
Cooking by crisping[6]			
King Edward 1	63.0	38.0	40
King Edward 2	39.0	16.5	58
Redskin 1	7.8	4.2	46
Redskin 2	16.5	10.1	39

[1] *Verfahren und Sorte – Traitement et variété*
[2] *Rückstand im ungekochten Fleisch – Résidu dans la chair crue*
[3] *Rückstand im gekochten Fleisch – Résidu dans la chair cuite*
[4] *Rückstand, durch das Kochen entfernt – Résidu éliminé par la cuisson*
[5] *Gesottene Knollen – Cuisson par ébullition*
[6] *Chips – Cuisson en chips*

Tabelle 3. Einfluss des Kochens auf die Rückstände von 2-Aminobutan in begasten Kartoffeln.
Tableau 3. Effet de la cuisson sur les résidus de 2-aminobutane dans des pommes de terre soumises à la fumigation.

crisp makers. The potatoes were halved, one half being crisped before analysis and the other analysed to determine the level of 2-aminobutane present before crisping. The results shown in Table 3 indicate that a mean of just under 50% of the residue was removed. However, the percentage removed was substantially higher if the loss of water was taken into consideration.

Processing

Fumigated potatoes were commercially processed into potato flakes and granules. During this process the potatoes were cooked and dehydrated and only required the addition of boiling water four times the weight of the flakes or granules to prepare them for eating. Analysis showed that 83 mg/kg 2-aminobutane was present in the dried flake, whereas, in three samples of granules there were 72, 64 and 125 mg/kg present. These figures appear high but the levels on the reconstituted potato ready for eating would be 17 mg/kg for the flake, and 15, 13 and 25 mg/kg for the granule samples.

It is concluded that, at present, fumigation of ware potatoes cannot be carried out because very significant residues remain after peeling, boiling, crisping or processing into flakes or granules.

Residues of 2-aminobutane in crops grown from fumigated seed potatoes

There must be no translocation of chemicals from mother to daughter tubers when treated seed is grown for ware (table) potato production. In 1968, crops were harvested which had been grown from seed potatoes treated at 140 mg/kg three days after lifting in 1967. In 1969 crops were harvested from seed treated at levels of 200, 500 and 1000 mg/kg three days after lifting in 1968. In 1970, crops were harvested from seed treated three and fourteen days after lifting in 1969 at 200 mg/kg. Results of the analyses of all these crops and untreated material from the same source are given in Table 4.

The residues found in crops grown from treated seed are very small and are not greatly different from those found in untreated material, even when the mother tubers had been treated with 2-aminobutane at five times the recommended dosage. There is, therefore, no significant translocation of the chemical to daughter tubers, so that there is no hazard to consumers of crops grown from treated seed.

Results of disease control by fumigation

Over the years 1967–'71, 29 fumigation treatments were carried out on bulks of tubers mostly in the 5-tonne prototype chamber. The experiments were designed firstly to determine the phytotoxic dose; secondly to establish the dose to obtain good control; and thirdly to determine the efficiency of the treatment at different times after lifting.

Phytotoxicity

In the early experiments (Graham and Hamilton, 1970), it was found that a dosage of 200 mg/kg tubers had no phytotoxic effects other than slight browning of skinned

Table 4. Residues of 2-aminobutane in crops grown from fumigated seed tubers.

Year[1]	Treatment of seed tubers[2]	Number of cultivars used[3]	Number of stocks used[4]	Range of residue (mg/kg)[5]	Mean residue (mg/kg)[6]
1968	140 mg/kg	2	2	0.05	0.05
	Nil[7]	2	2	0.05	0.05
1969	200 mg/kg	3	4	0.04–0.12	0.08
	500 mg/kg	1	1	0.09–0.16	0.14
	1000 mg/kg	1	1	0.05–0.11	0.08
	Nil	3	4	0.03–0.11	0.07
1970	200 mg/kg (3 days)	2	2	0.01–0.10	0.05
	200 mg/kg (14 days)	2	2	0.01–0.06	0.03
	Nil	2	2	0.01–0.04	0.03

Limit of detection of 2-aminobutane 0.01 mg/kg – *Grenze der Nachweismöglichkeit von 2-Aminobutan 0,01 mg/kg – Limite de détection de 2 aminobutane 0,01 mg/kg*
Standard deviation 0.03 mg/kg – *Standardabweichung 0,03 mg/kg – Déviation standard 0,03 mg/kg*

[1] *Jahr – Année*
[2] *Behandlung von Pflanzknollen – Traitement des plantes*
[3] *Anzahl der verwendeten Sorten – Nombre de variétés utilisées*
[4] *Anzahl der verwendeten Partien – Nombre de stocks utilisés*
[5] *Rückstandsbereich – Niveau de résidu*
[6] *Mittlerer Rückstandswert – Quantité moyenne de résidu*
[7] *Keine – Nul*

Tabelle 4. Rückstände von 2-Aminobutan im Nachbau von begasten Pflanzknollen.
Tableau 4. Résidu de 2-aminobutane dans les récoltes issues de plants soumis à la fumigation.

areas. To determine the phytotoxic level, three separate lots of about 300 tubers of cv. *Majestic* were treated at dosages of 500, 1 000 and 5000 mg/kg. More marked browning of skinned areas was observed at the 500 mg/kg level, whereas at 1 000 mg/kg there was some lenticel pitting and very marked browning of damaged areas. At the 5000 mg/kg dosage chemical damage was severe and all eyes on the tubers were killed.

Immature and badly skinned tubers were, however, injured even at the 200 mg/kg dose, thus emphasising the need for treating only mature tubers.

Control of gangrene, skin spot and silver scurf by fumigation at different dosages at different times after lifting

Experiments with organomercury disinfectant solutions have shown that, in general, the longer the delay between harvesting and treatment, the poorer the degree of disease control. This probably results from changes in the skin, especially suberisation, making it increasingly impervious to the dipping solution.

By analogy, it seemed likely the same principle would apply to 2-aminobutane, so experiments were done at times varying from 1 to 30 days after lifting at dosages from

50 mg/kg to 200 mg/kg. In every case, fumigant was introduced in 30–40 min, and recirculation continued for a further 2 h. Tubers dug by elevator digger were received from various farms in bags. The farms were chosen on the basis that past experience had shown crops grown there were more likely to be affected by gangrene or skin spot than crops grown in other areas, which avoided having to use artificially inoculated material. In the early experiments tubers were not graded before treatment but later, tubers graded over a spool grader were used. After fumigation tuber samples taken from different positions in the chamber were stored in 0.5-tonne bulks under straw in a cool (5–8 °C) but frost-proof shed until February when the tubers were placed in trays to sprout in a warmer shed where the temperature varied between 9–15 °C. Assessments of rots were made on two occasions, once in February and again just before planting in April, whereas the skin diseases skin spot and silver scurf were assessed on washed samples of 50 or 100 tubers in April. Diseases were identified by symptoms but the diagnoses were checked by isolation from representative tuber samples. Some tests were also made using the eye plug method for skin spot, the eye plugs being incubated in moist chambers and examined microscopically for *Oospora pustulans* (Hide et al., 1968), which confirmed the presence or absence of viable skin spot fungus on treated material. For controls, 0.5-tonne bulks were stored and handled similarly, except that they were not loaded into and out of the chamber.

Results of the treatments on gangrene and skin spot are shown in Table 5; for simplicity the degree of skin spot infection is expressed only as the surface infection index (Boyd, 1957).

In one experiment the efficiency of 2-aminobutane at 200 mg/kg dosage was compared with dipping in a solution of methoxyethylmercuric chloride (MEMC) containing 100 mg of mercury per kg. Results are given in Table 6.

Control of silver scurf is shown by results given in Table 7.

Discussion

Our studies show that fumigation of potato tubers can be done easily in a simply made chamber fitted with a vaporiser and gas recirculation system.

The biological results illustrate the great efficiency of 2-aminobutane in controlling gangrene and skin spot at a dosage of 200 mg/kg. It is noteworthy that where gangrene did develop in fumigated material, it was often associated with severe mechanical damage, and such tubers would usually be removed at dressing in any case. Results of treatment at 50 mg/kg indicate that it is too low a dosage, and although only a few treatments were done at 100 mg/kg, there are indications that this dosage is sufficient to achieve satisfactory control. However, bearing in mind that, in commercial practice, the gas may not become equally distributed throughout the bulk, for instance as a result of the presence of soil, a dosage rate of 200 mg/kg is recommended. Like organomercury disinfectant solutions, best results for control of gangrene, skin spot and silver scurf were obtained if fumigation was done within three days of lifting, but even after 14 days the degree of control of both gangrene and skin spot was good at

Table 5. Results of experiments to test efficiency of treatment with 2-aminobutane at different dosages and different times of lifting on the incidence of gangrene and skin spot.

Date of lifting[1]	Cultivar[2]	Dosage mg/kg[3]	Number of days elapsed between harvest and treatment[4]	Number of tubers examined[5]	Percentage gangrene[6]	Skin spot surface infection index[7]
22.10.68	*Majestic 1*	200	1	1328	0.2	0.03
		nil[8]	–	1376	4.1	11.20
23.10.68	*King Edward 1*	200	1	1605	0.1	0
		nil	–	1458	5.8	9.4
13.11.68	*Redskin 1*	200	2	552	0.7	0
		nil	–	567	88.6	0
7.10.69	*Redskin 2*	200	1	1844	0.2	0
		200	14	2258	0.2	0.03
		nil	–	1957	5.0	5.60
15.10.69	*King Edward 2*	200	1	1869	0.4	0
		200	14	2202	0.7	0.03
		nil	–	2053	2.0	3.25
7.10.70	*King Edward 3*	50	2	2057	1.8	0.03
		100	2	1986	1.1	0
		200	2	2057	0.2	0
		50	13	2275	3.3	0
		200	13	2177	0.5	0.06
		50	27	2163	4.9	0.10
		200	27	2113	1.0	0.16
		nil	–	2657	8.1	9.15
13.10.70	*Redskin 3*	50	1	732	0.1	0
		100	1	708	0	0
		200	2	748	0	0
		50	14	727	0.1	0.03
		200	14	735	0	0
		50	30	743	0.1	0.16
		200	30	747	0.1	0.32
		nil	–	798	2.7	7.37
10.12.70	*Red Craigs Royal 1*	50	5	880	36.8	0.19
		200	5	874	13.8	0.09
		nil	–	334	79.6	3.63
10.12.70	*Majestic 2*	50	3	1104	1.4	0.48
		200	3	1137	0.2	0.25
		nil	–	443	7.7	4.09
1.10.71	*King Edward 4*	50	1	2153	0	0.06
		200	1	2123	0	0
		50	29	2328	0	0.19
		200	29	2383	0	0.25
		nil	–	1867	0.2	3.84

Table 6. Effectiveness of 2-aminobutane fumigation compared with methoxyethylmercuric chloride (MEMC) disinfectant solution in controlling gangrene.

Cultivar[1]	Treatment[2]	Number of tubers examined[3]	Percentage gangrene[4]
Majestic	2-aminobutane	227	4.8
	MEMC	754	6.1
	nil[5]	195	33.3
Redskin	2-aminobutane	291	7.2
	MEMC	314	15.0
	nil	329	43.4

[1] *Sorte – Variété*
[2] *Behandlung – Traitement*
[3] *Anzahl untersuchter Knollen – Nombre de tubercules examinés*
[4] *Prozent Phoma-Knollenfäule – Pourcentage de gangrène*
[5] *Null – Nul*

Tabelle 6. Wirksamkeit von 2-Aminobutan-Begasung, verglichen mit der Desinfektionsmittellösung Quecksilbermethoxyäthylchlorid für die Bekämpfung von Phoma-Knollenfäule.
Tableau 6. Efficacité de 2-aminobutane en fumigation comparée au chlorure de méthoxyéthylmercurique en solution dans la butte contre la gangrène.

the 200 mg/kg dosage rate. After about one month the treatment was less efficient, though, even so, control of gangrene and skin spot was still reasonably good. Control of silver scurf was always poorer than with gangrene and skin spot and results of delaying treatment after harvest are especially well illustrated by this disease (Table 7). In commercial practice, fumigation within 14 days of harvest is recommended, allowing more time for lifting, grading and handling, than in the case of organomercury dips where treatment is recommended to be done within 3 days of lifting. The reason why 2-aminobutane remains effective for a longer time is probably, at least in part, a

◀
[1] *Erntedatum – Date d'arrachage*
[2] *Sorte – Variété*
[3] *Dosis – Dose*
[4] *Anzahl verflossener Tage zwischen Ernte und Behandlung – Nombre de jours entre la récolte et le traitement*
[5] *Anzahl untersuchter Knollen – Nombre de tubercules examinés*
[6] *Prozent Phoma-Knollenfäule – Pourcentage de gangrène*
[7] *Index für Befall mit Tüpfelfleckigkeit (Oberfläche) – Index de surface infectée d'oosporiose*
[8] *Null – Nul*

Tabelle 5. Ergebnisse von Versuchen, die Wirksamkeit von Behandlungen mit 2-Aminobutan bei verschiedener Dosierung und unterschiedlichen Erntezeiten auf den Befall mit Phoma-Knollenfäule und Tüpfelfleckigkeit zu testen.
Tableau 5. Résultats de tests d'efficacité de traitements au 2-aminobutane à différentes doses et différentes époques après l'arrachage sur les manifestations de gangrène et d'oosporiose.

Table 7. Control of silver scurf by fumigation with 2-aminobutane.

Cultivar[1]	Treatment[2]	Percentage skin cover with silver scurf[3]
King Edward	200 mg/kg 2 days after lifting[4]	13.1
	200 mg/kg 29 days after lifting	41.6
	nil[5]	71.6
Pentland Crown	200 mg/kg 2 days after lifting	18.4
	200 mg/kg 29 days after lifting	31.8
	nil	47.1

[1] *Sorte – Variété*
[2] *Verfahren – Traitement*
[3] *% mit Silberschorf bedeckte Schale – Pourcentage de peau couverte de gale argentée*
[4] *Tage nach der Ernte – Jours après l'arrachage*
[5] *Null – Nul*

Tabelle 7. Bekämpfung von Silberschorf durch Begasung mit 2-Aminobutan.
Tableau 7. Le traitement de la gale argentée par fumigation avec le 2-aminobutane.

reflection of penetration of the skin in which the fungi occur. In mature, fully suberised tubers of the cv. *Majestic* more than 90% of methoxyethylmercuric chloride is contained within the first millimetre of peel (Hamilton and Ruthven, 1967) whereas only 60–70% of 2-aminobutane is contained within the first millimetre.

The experiment comparing the efficacy of 2-aminobutane with a methoxyethylmercuric chloride dip shows that 2-aminobutane is the more effective (Table 6). Even so the results with 2-aminobutane were poorer than expected, probably due to the fact that treatments were done in a small chamber where distribution of the gas was uneven.

Experience has shown that control of gangrene by organomercurial dipping solutions can prove more difficult with tubers lifted very late in the season. The reason for this is not clear, but it may be due to poorer penetration because the skin has become more impervious or because the infection has become more deep-seated by then, or perhaps for both reasons. To see if the same problem would arise with 2-aminobutane, a stock of cv. *Red Craigs Royal* (*Red Craigs Royal* 1 in Table 5) and a stock of cv. *Majestic* (*Majestic* 2 in Table 5) were obtained from an area in N.E. Scotland in December. The *Red Craigs Royal* untreated tubers developed nearly 80% gangrene, while fumigation five days after lifting at 200 mg/kg reduced the loss to around 14%. This is not as good a control as in other experiments, but, even so, fumigation would prove to be economically well worth while in such cases.

The effect of treatments on sprouting, growth and yield of tubers will be described elsewhere, as field trials are still in progress. However, experience over four years with several cultivars shows that, in general, 2-aminobutane treatment causes more sprouts to develop on tubers, thus there are more stems per plant and a greater proportion of

smaller (mainly seed size tubers) are produced as compared with healthy untreated tubers. Yields obtained from treated tubers generally have either been the same as, or greater than, those from untreated tubers. These effects are comparable with results obtained with organo-mercury disinfectant solutions (Boyd and Penna, 1967).

Treatment with 2-aminobutane did not control tuber blight (caused by *Phytophthora infestans*), dry rot (*Fusarium solani* var. *caeruleum*), nor did it kill the sclerotia of *Rhizoctonia solani*. Its effect on other tuber diseases is not yet known.

Experiments are continuing, present work concentrating on the efficiency of fumigation when tubers are treated after grading in February. Investigations are also being made on the degree to which the crops grown from treated seed are infected with gangrene, skin spot and silver scurf fungi.

The use of 2-aminobutane for fumigation of seed potatoes has been patented in the United Kingdom (patent specification 1268490) and in Eire. Fumigation has been cleared for safety under the British Pesticides Safety Precautions Scheme for use on seed potatoes. It must not be used on ware (table) potatoes.

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Zusammenfassung

Anwendung von 2-Aminobutan als Räuchermittel zur Bekämpfung von Phoma-Knollenfäule, Tüpfelfleckigkeit und Silberschorf von Kartoffelknollen

Jedes Jahr können Pilzkrankheiten an Kartoffelknollen beträchtliche Verluste verursachen. In Schottland ist die Phoma-Knollenfäule, verursacht durch den Pilz *Phoma exigua* var. *foveata*, die bedeutendste Krankheit, doch ist die Tüpfelfleckenkrankheit, hervorgerufen durch *Oospora pustulans*, ebenfalls wichtig, vor allem weil sie die Keime befällt. Silberschorf, verursacht durch *Helminthosporium solani*, ist sehr verbreitet, aber obwohl er die Keime nicht befällt, werden durch ihn die Knollen missgebildet, und er verursacht Welke infolge des Wasserverlustes durch die beschädigte Schale.

Begasung von Knollen mit 2-Aminobutan (sek-Butylamin)-Dampf in einer Dosierung von 200 mg/kg innerhalb 14 Tage nach der Ernte wurde als ein sehr gutes Mittel zur Bekämpfung von Phoma-Knollenfäule und Tüpfelfleckigkeit (Tabelle 5) befunden. In zwei Versuchen ergab die Begasung eine bessere Bekämpfung von Phoma-Knollenfäule als das Eintauchen in eine Lösung von Quecksilbermethoxyäthylchlorid, das 100 mg/kg Quecksilber enthält (Tabelle 6). Eine gewisse Bekämpfung der Silberschorfkrankheit wurde mit 2-Aminobutan erzielt (Tabelle 7), aber die Ergebnisse waren immer schlechter als bei Phoma-Knollenfäule und Tüpfelfleckigkeit. Phytophthora-Knollenfäule (*Phytophthora infestans*) und Fusarium-Trockenfäule (*Fusarium solani* var. *caeruleum*) wurden durch die Begasung nicht bekämpft, und auch auf die Sklerotien von *Rhizoctonia solani* hatte die Begasung keinen Einfluss. Die Beurteilung der Fäulen wurde an zwei Terminen vorgenommen, einmal im Februar und dann wieder im April, während die Schalenkrankheiten, Tüpfelfleckigkeit und Phoma-Knollenfäule im April an gewaschenen Mustern von 50 oder 100 Knollen beurteilt wurden. Der Bau der Gaskammern (dargestellt in Abb. 1 und 2) wird kurz beschrieben und der Vorgang der Begasung diskutiert. Die Kammern sind für Gas-Innenkreislauf eingerichtet, das

System ist verbunden mit einem Gebläse und einem Verdampfer. Da das 2-Aminobutan-Luftgemisch durch einen losen Kartoffelhaufen dringt, wird die Chemikalie von den unteren Knollenschichten aufgenommen; aber da der Innenkreislauf anhält, findet eine Abgabe und Wiederaufnahme statt, so dass der Wirkstoff, wie sich bei Rückstandsanalysen gezeigt hat, möglicherweise gleichmässig im Haufen verteilt wird. Es wurde festgestellt, dass bei einer Dosis von 200 mg/kg in 30–40 Minuten und bei Luftumwälzung während weiteren zwei Stunden die Rückstände in Knollenmustern von unten und oben im Haufen ähnlich waren (Tabelle 1).

Rückstände von 2-Aminobutan waren in signifikantem Ausmass vorhanden in geschälten (Tabelle 2) und gesottenen Kartoffeln sowie in Chips (Tabelle 3), ferner in Flocken und Granulaten, die aus begasten Kartoffeln hergestellt wurden, so dass das Verfahren nur bei Pflanzkartoffeln angewendet werden kann. Analysen des Nachbaus von behandelten Knollen zeigte, dass sie keine signifikanten Rückstände enthalten (Tabelle 4).

2-Aminobutan wird leicht verdampft (Siedepunkt 63 °C) und ist schwach giftig; die Giftigkeit beruht in erster Linie auf seiner Alkalinität. Gewisse Vorsichtsmassnahmen müssen getroffen werden, wenn diese Substanz zur Begasung von Kartoffeln verwendet wird; sie sind in einer formellen Gebrauchsanweisung beschrieben, die von den Autoren bezogen werden kann.

Résumé

L'utilisation du 2-aminobutane en fumigation par le traitement des maladies de la gangrène, de l'oosporiose et de la gale argentée des tubercules de pomme de terre

Les maladies fongiques des tubercules de pomme de terre peuvent occasionner des pertes annuelles considérables. En Ecosse, la gangrène, causée par le champignon *Phoma exigua* var. *foveata*, est la maladie la plus grave mais, l'oosporiose, causée par *Oospora pustulans*, est également importante, spécialement quand elle attaque les germes. La gale argentée, causée par *Helminthosporium solani*, est très commune, mais bien que n'attaquant pas les germes, elle détériore l'aspect des tubercules et provoque leur ramolissement par suite de la perte d'eau au travers de la peau endommagée.

On a trouvé que la fumigation des tubercules avec la vapeur de 2-aminobutane (sec-butylamine), à la dose de 200 mg/kg dans les 14 jours qui suivent l'arrachage avait une très bonne efficacité dans la lutte contre la gangrène et l'oosporiose (tableau 5); de plus, dans deux essais, le résultat du traitement contre la gangrène a été supérieur au trempage dans une solution du chlorure de méthoxyethylmercurique à 100 mg/kg de mercure (tableau 6). Le 2-aminobutane a donné certains résultats dans le traitement de la gale argentée (tableau 7), mais ceux-ci sont toujours inférieurs à ceux obtenus contre la gangrène et l'oosporiose. La fumigation n'a aucun effet contre le mildiou du tubercule (*Phytophthora infestans*) et la pourriture sèche (*Fusarium solani* var. *caeruleum*), pas plus que contre les sclérotes du *Rhizoctonia solani*. La détermination des pourritures a été faite deux fois, une première fois en février et une seconde en avril, tandis que les déterminations des maladies de la peau, oosporiose et gangrène, ont été effectuées en avril sur des échantillons lavés de 50 ou 100 tubercules.

Les auteurs décrivent brièvement la construction des chambres de fumigation (voir fig. 1 et 2) et expliquent le mécanisme de fumigation. Les chambres sont équipées pour la circulation forcée du gaz, grâce à un ventilateur et un vaporisateur. Au moment où le mélange air – 2-aminobutane traverse le tas de pommes de terre, la substance chimique est absorbée par les couches inférieures de tubercules, mais grâce à la circulation forcée, il se produit des phénomènes de 'désaborption' et de 'réabsorption' de telle sorte que, finalement, la substance chimique se répartit d'une manière égale dans la masse de tubercules, comme l'indique l'analyse des résidus. Il a été démontré que si on applique la dose de 200 mg/kg pendant 30–40 minutes et qu'on réalise la circulation forcée pendant un minimum de 2 heures, les résidus dans les échantillons de tubercules sont identiques de la base au sommet du tas (tableau 1).

Les résidus de 2-aminobutane sont présents en quantités significatives dans les tubercules

pelés (tableau 2), bouillis et transformés en chips (tableau 3), de même dans les flocons et granulés fabriqués à partir de pommes de terre traitées, de sorte que le traitement ne peut s'appliquer qu'aux plants. L'analyse des récoltes issues de plants traités ne révèle aucune quantité significative de résidu (tableau 4).

Le 2-aminobutane se vaporise aisément (63 °C), est modérément toxique, la toxicité étant due en premier lieu à l'alcalinité. Il y a lieu de prendre certaines précautions dans l'emploi de cette substance dans la fumigation des pommes de terre, qui sont décrites dans le code d'emploi officiel que les auteurs peuvent fournir.

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