Gentle Harvest of Potatoes in Storage Boxes

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ABSTRACT

In order to guarantee a gentle handling of potatoes that maintains the quality of the product, potatoes are filled into storage boxes at the harvest stage. The filled storage boxes are transported to and deposited in the store. The potatoes are not exposed to any handling processes or mechanical stress.

In order to fill the storage boxes on board the harvester, a filler has been developed and tested for three harvest periods. The method of filling the storage boxes on board the harvester was compared with two conventional procedures. The evaluation criteria used to compare the methods were amongst others: respiration intensity, black spots and the costs involved.

As expected using the gentle filling process directly on the harvester the number and intensity of impacts can be reduced. Mainly potato varieties with high susceptibility showed lower respiration intensities and reduced grades of black spot development.

The slightly higher process costs can be justified because of high quality of the tubers.

Keywords: potatoes, harvest, storage boxes, quality, costs, black spots

1. INTRODUCTION

Potatoes contribute a significant role to the human nutrition in many countries all over the world. The amount of potato consumption in Germany is 67 kg fresh weight per caput and year (anonym, 2004). The average consumption in Europe amounts to 75.5 kg (anonym, 2004). In average within three years from 2001 to 2003 the total crop production in Germany was 10.8 million tonnes (anonym, 2004).

An efficient crop production requires high mechanized processes in all production stages. Therefore, potatoes are handled several times during harvesting, transport and storage. Each handling operation leads to mechanical damages depending on the height of fall and the number of drops involved.

These damages cause substantial economic losses on the fresh market and the potato processing industry. The damages lead to additional costs due to higher respiration intensity accompanied with weight loss during the storage period, higher susceptibility to spread of diseases and a higher level of waste material during processing of the tubers. Cobb (1999) reported about costs of £30 million in UK, i.e. £200 for every hectare of crop caused by damages.

One of the most serious defect problems is the occurrence of black spots. A lot of investigations took place the recent years to examine the reason for formation of black spot and the susceptibility of the potato tubers for black spot development on mechanical impacts. It was established that the black spot development depends among others on physical, physiological and biochemical properties of the tuber. Other important influence parameters are genotype, development and environment (McGarry et al., 1996).

Although all the interrelations are understood better now the reduction of mechanical stress is the best way to avoid black spot. In consideration of this fact a gentle handling of potatoes from the harvest to the storage has to be achieved. One possibility to reduce the mechanical stress on potatoes is to find new handling methods during the transport and storage of potatoes in storage boxes. In order to be able to use all advantages of the box filling and using procedure the potato tubers have to be filled gently into storage boxes directly on board of the harvester.

2. STATE OF RESEARCH

Currently, two methods of harvesting are widely used: The harvested potatoes are passed via a discharge belt onto a transport vehicle which is driving alongside the harvester or the potatoes are collected in a hopper on board the harvester. When the hopper is full, the contents are transferred to the transport vehicle, either on the field or at the edge of the field. At the storage hall the tubers are tipped out, separated of soil and stones as far as possible and brought into storage via a conveyer belt system. During each handling stage (Table 1) the potatoes are exposed to mechanical stress which leads to damage.

The most damages occur during processing (33.1%) but the farmer often cannot affect these damages. Important for the farmer is the question, who can he reduce the damages from harvest until end of the storage. In total two-thirds of the damages occur from harvest until end of the storage.

Table 1. Proportion of damages per handling stage to total damages (Bouman, 1995)

Handling Stage	Damages (%)
1. Harvest	14.7
2. Transport and interim storage	0.5
3. Conveyer belt and stationary filler	1.5
4. Storage	20.8
5. Removal of potatoes	12.2
6. Loading lorry	14.2
7. Unloading lorry	3.0
8. Processing (sorting to packing)	33.1

To avoid damages caused by handling, transport and storage, farmers are tending to fill the potatoes into storage boxes immediately after harvesting (Peters, 1992; Bouman, 1994; Kern, 1998). The boxes are brought to the fields in transport vehicles and filled by the harvester. Bouman (1994) reports of a technical solution for filling small containers on board the harvester.

In a large number of studies the effects of actions influencing product quality during harvesting and subsequent processes are evaluated using defined criteria.

Electronic measuring sensors have been in use for many years to measure the acceleration resulting from impact stresses (Peters, 2001; Leppack, 1995b; Demmel et al., 2004; Expido et al., 2004) or pressure loading (Herold et al., 1995) on the potato. An acceleration sensor is in development which can be implanted into the potato in order to ensure an improved measurement of the stresses on the actual tuber (Herold et al., 2004).

Mechanical impact stresses lead to damages, which are differentiated by the degree of damage, by the state of the damaged tissue and the way in which the damage occurred (McGarry et al., 1996; Lærke, 2001; Schuhmann, 1998).

Black spots are a particularly serious defect. The terminology used is not always consistent. Discolouration ranges from blue-grey to black and is called blue spot or black spot. Blue spots and black spots could be of different origin; usually it is assumed that the same chemical mechanism is the cause of both (Wirsing, 2001; Leppack, 1995a).

Black spots are often used to assess how gently potatoes were handled in the processing chain or in the individual processing stages themselves (Molema, 1999; Leppack, 1995b; Van Canneyt, 2004). Significant is the time at which the tubers are examined for black spots. Peters (2001) points out that damages to freshly harvested tubers at the first stage may lead to discolouration and subsequently to grey white necroses. In stored tubers on the other hand, damages often result in permanent discolouration. Due to these different reactions, distinctions must be made between the times that a particular variety of potato is most sensitive: at the time of harvest (lifting damage) or storage (storage damage) or at both times.

It can usually be assumed that a high danger of damage results from strong impacts. But studies of series of impacts have shown that many small impacts may already result in damages (Leppack, 1995b; Molema, 1999).

The respiration intensity of the potato gives further indication of impact stress. This means the development of CO_2 in potatoes, where a high CO_2-Development points to high mechanical stress (Meinl, 1972; Peterson et al., 1981; Aeppli, 1979).

Aeppli (1979) subjected tubers to stress in a shake test and found a correlation coefficient of $r = 0.83$ between the black spot index and the respiration intensity. The highest respiration intensity occurred 2-3 days after stress, but clear differences according to the variety of potato could be observed only a few hours after stress. Meinl (1972) determined the respiration intensity 24 hours after stress occurred, Peterson et al. (1981) after only 16 hours.

Other important factors influencing the respiration intensity are the ripeness of the tubers, the duration of storage, the dry matter content and above all the temperature of the tuber (Hunter, 1985; Peterson et al., 1981; Meinl, 1972; Schander et al., 1931).

Carrots also demonstrated an increase in respiration intensity after stress occurred depending on the intensity of stress. The maximum was reached after only 10 to 12 hours (Mempel, 2000).

3. AIM

The objective is to avoid mechanical stresses on the harvested potatoes as far as possible, by transferring the potatoes into storage boxes on board the harvester. The boxes are transported to the storage building and stored. In a comparison of methods, the advantages of filling the boxes on board the harvester for handling, transport and storage of the tubers as well as for quality assurance will be shown by using selected criteria.

This paper only reports on harvesting and the transfer of the potato tuber onto the transport vehicle. A second paper will follow covering the box storage.

4. MATERIAL AND METHODS

For the field experiment a 2-row harvester Grimme SE 150 - 60 was equipped with a device for filling and transferring the box (Figure 1). The box is held on the harvester by a base frame that is moveable laterally. At the start of filling, the filling belt is lowered to the bottom of the box and raised step by step during the filling process. The filling belt is moveable in the direction of travel and the box crossways. This ensures that the box can be filled evenly over its entire base area. When the box is full the base frame is moved sideways to the transport vehicle and the box transferred like a container (Scheibe et al., 2004). To counteract floor unevenness the base frame beneath the box may be tipped sideways (Figure 1).

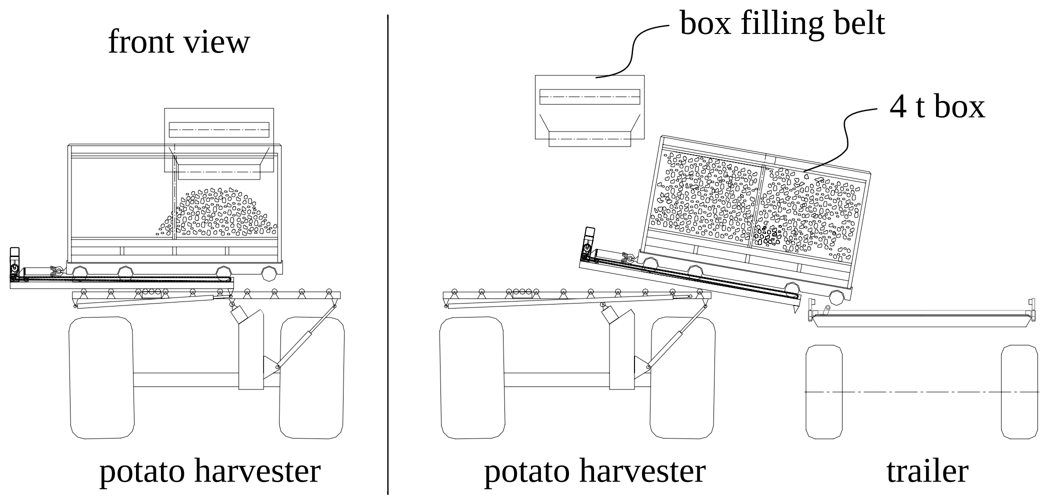

Figure 1. Schematic representation of the box on the harvester in the filling position and the transfer of the box

Developed by: Schoepstal Maschinenbau GmbH and Verkehrstechnologie Thüringen GmbH Erfurt, Germany (Scheibe et al., 2004)

A comparison of methods studied the following three methods in an agricultural enterprise for three harvest periods:

1. Bulk Storage: The tubers are filled from the hopper of the harvester onto the loading area of the transport vehicle and transferred to a section store (Figure 2a). In the section store the tubers are tipped out and stored as bulk product.

2. Indirect box filling: The lifted potatoes are collected on the harvester in a 6 t hopper, then filled into the large box on the adjacent transport vehicle and transported into the storage hall (Figure 2b).

3. Direct box filling: The potatoes are filled into 4 t boxes while still on the harvester, then the box is transferred from the harvester onto the transport vehicle and taken into the storage hall (Figure 2c).

In all three methods the transport vehicles drive onto the field for transferral to take place.

a) b) c)

Figure 2. Variations of transferring tubers onto the transport vehicle examined: a) bulk storage, b) indirect box filling, c) direct box filling

To ensure comparable lifting conditions, all three methods were used simultaneously on the same potato fields.

In the years 2002 - 2004 the potato varieties: Solara, Likaria, Sanira, Donella, Marena und Möwe were studied. For these varieties, 528 large boxes were each filled with 4 t of potatoes and stored. Additionally the same varieties were stored in a section store as bulk storage.

The following characteristics were established to compare the methods:

The **level of mechanical stress** at harvest, transfer and storage of tubers was measured by the pressure measuring sphere PMS 60 from the Institute of Agricultural Engineering Bornim e.V. (Germany). Each measurement was repeated five times.

The **internal damage** of the potatoes was determined three weeks after the beginning of storage by a visual inspection (Peters, 1999) after cutting the tubers:

- up to 1/4 of the circumference, up to a depth of 5 mm ⇒ no discolouration
- up to 1/2 of the circumference, up to a depth of 5 mm and/or up to 1/4 of the circumference and deeper than 5 mm ⇒ medium discolouration
- more than 1/2 of the circumference, up to a depth of 5mm and/or up to 1/2 of the circumference and deeper than 5 mm ⇒ strong discolouration

Black spots and necroses of medium and strong degrees were counted as internal damage. Of each potato variety and harvesting method 100 kg of tubers were evaluated, 1200 kg in total.

Respiration intensities were determined in closed cuvettes in a saturation procedure using CO_2 sensors from the company Ahlborn (Type FYA600CO2). Due to reasons of labour organisation – as measurements had to be taken in an agricultural enterprise – the respiration intensity was measured only five hours after harvesting. Samples of each variety were taken at the same time from all three harvest methods. Therefore all samples of one variety had the same temperature. According to studies by Meinl (1972) and Aeppli (1979) the maximum respiration intensity cannot be expected to have been reached 5 hours after stress. However,

in the present study, maximum respiration intensities were not vital, rather the differences between samples as a result of the differing impact stresses.
1 kg of externally undamaged tubers was passed into cuvettes. The measuring period was 1 hour. The respiration intensity for potatoes lifted by hand was also measured as a reference value. All measurements were repeated three times.

Labour time was measured and **operation costs** calculated for lifting and for transferring either the tubers onto the transport vehicle (whether the loading area or box) or the box from the harvester to the transport vehicle.

5. RESULTS

As expected, the measurements with the artificial measurement sphere PMS 60 showed number and intensity of impacts could be reduced by directly filling the boxes in comparison to the two other methods (Figure 3).

One result of the reduced impact stress was that direct box filling produced the least degree of discolouration (black spots, necroses) of tubers (Figure 4). The difference becomes particularly apparent for the sensitive variety Möwe. In this case only 11 % of tubers exhibited black spots compared with 20 % for the bulk storage method. As the damages were already measured three weeks after storage, they could only have been caused by lifting, handling and storing (bulk form).

Horlacher et al. (2004) compared box filling on the field, box filling on the farmyard and handling tubers as bulk. The study revealed that the comparatively highest stress and the most damages occurred when filling 1 t boxes on the field (indirect filling). The number of damages was noticeably reduced only when larger 3 t boxes were filled. Large boxes have the advantage that in relation to the total content of the box there are fewer tubers at the edge of the box that could be damaged by the walls of the container. Furthermore, by using large boxes filling equipment may more easily be lowered completely to the floor of the container reducing the falling height of tubers. This means that not only the use of box filling but also the dimensions of the box used and the filling equipment are significant in reducing the damages that occur.

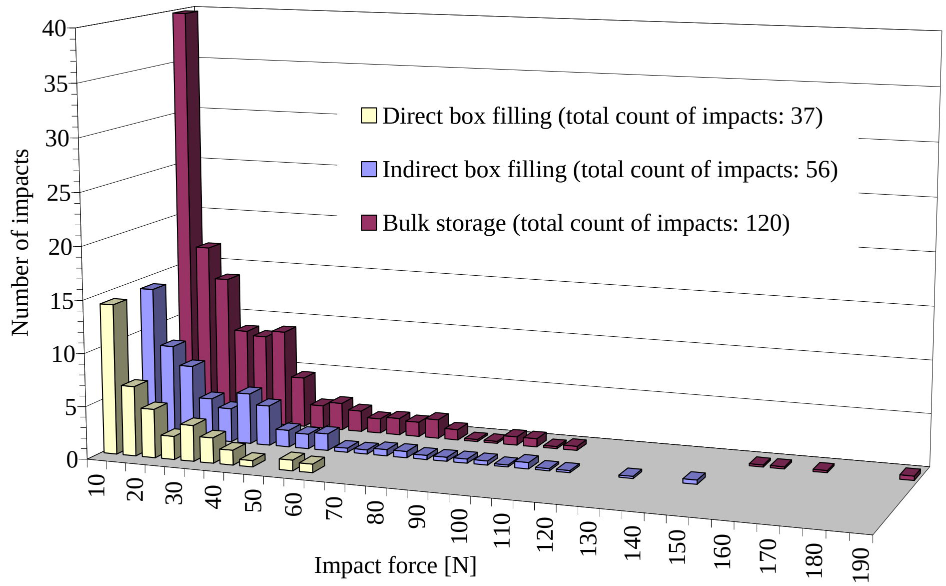

Figure 3. Intensity of impacts from the sorting belt to the store
Impacts from the digging share to the sorting belt not represented.
Average of 5 measurements.

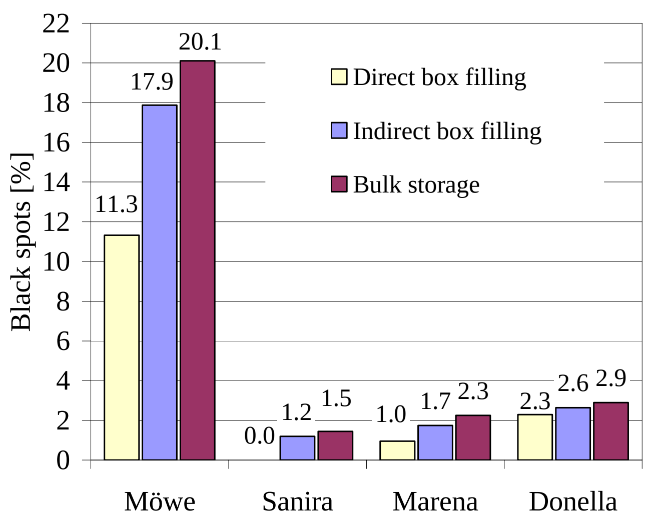

Figure 4. Black spots three weeks after storage
100 kg per variety and method.

The respiration intensity is also an indication of low mechanical stress of the tubers when direct box filling is used. Although the differences are not significant for all varieties, direct box filling always has the lowest values of the three methods (Figure 5). The respiration intensity was only lower for tubers lifted by hand.

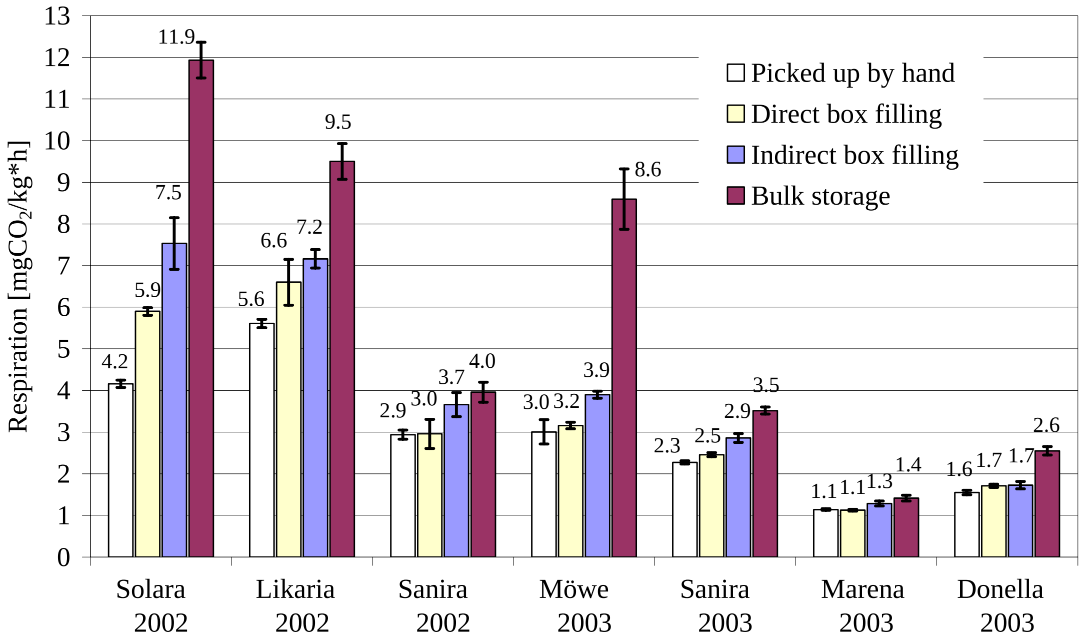

Figure 5. Respiration intensity of the potato immediately after harvest.
Average of three measurements with standard deviation.

On average, 102 seconds (90 to 120 s) per box handling (4 t) is needed for direct box filling (Table 2). Measurements were always started when the transport vehicle reached the rear of the harvester. Time measurement includes:

- Positioning the transport vehicle next to the harvester,
- Transferral of full boxes onto the transport vehicle,
- Movement of transport vehicle by one containers length.
- Transferral of an empty box onto the harvester.

Due to the positioning of the transport vehicle and the twofold box transferral, the highest specific labour time occurs for direct box filling: 26 s per tonne of potatoes (Figure 2). The complete box transfer (full box onto vehicle + empty box onto harvester) takes only 55 s on average.

For lifting, turning and transfer of the tubers, a labour time of 1.72 to 1.81 h/ha was measured (Table 2). The differences between the methods examined are thereby slight. The higher labour time needed for transferring the boxes is barely of consequence.

Table 2. Measured labour time for lifting and transfer of harvested potatoes

		Bulk storage	Indirect box filling	Direct box filling
Mass per transfer	T	6	4	4
Positioning means of transport [*]	S	16 ± 2.97	20 ± 5.07	47 ± 10.77
Box transfer (full+empty) [*]	S			55 ± 8.60
Tuber transfer [*])	S	69 ± 14.81	58 ± 12.73	
Total Tuber transfer[*]	S	85 ± 14.91	78 ± 13.70	102 ± 13.78

Specific labour time for tuber transfer[*]	**s/t**	**14 ± 2.78**	**19 ± 3.42**	**26 ± 3.44**
Labour time for lifting, turning and transfer	h/ha	1.72	1.75	1.81

[*] Mean value of 15 measurements ± standard deviation

As to be expected the highest process costs result from the direct box filling of containers at 328.66 €/ha (Table 3). The reasons for this are the higher initial costs and the slightly higher labour time required. Bulk storage and indirect box filling result in approximately equal costs. Details of spending on storage, in particular the costs of the boxes and forklift trucks will be reported at a later date.

The cost calculation does not account for the advantage that the quality of tubers from the direct box filling is better than that of the tubers of the other two methods. It is up to the distributor to obtain higher earnings due to better product quality.

Table 3. Process costs for lifting and transfer

		Bulk storage	Indirect box filling	Direct box filling
Initial cost of harvester	T€	83	83	98 [1]
Area capacity	ha/h	0.58	0.57	0.55
Harvester [2]	€/ha	169.95	169.95	194.70
Tractor and driver [3]	€/ha	67.69	69.72	72.02
4 workers[4]	€/ha	58.21	59.96	61.94
Total lifting	€/ha	295.85	299.63	328.66
	€/t 5)	8.45	8.56	9.39

[1] expected initial cost [2] 8 years use, 100 ha/a [3] 24.80 €/h + 14.62 €/h=39.42 €/h
[4] 4 x 8.48 €/h=33.92 €/h [5] 35 t/ha yield

6. CONCLUSIONS

Special equipment has been developed and tested for filling storage boxes on board the harvester. Due to the gentle filling of the boxes on board the harvester the extent of mechanical stresses is reduced slightly in comparison to the indirect box filling method and evidently to the loos storage.

The tubers which are less stressed exhibit low respiration intensity and less discolouration due to impacts. In the case of varieties with high susceptibility, it is possible to reduce the grade of black spots to half amount.

In average, the transfer time of the boxes from the harvester to the trailer and backwards is 102 seconds long, including the time for the positioning of the transport vehicles. This is more time needed for the transfer of the potatoes by the other methods. But the additional time is not significant in relation to the whole process including lifting and turning.

The longer transfer times of the box from the harvester to the transport vehicle as well as the higher initial cost of the harvester result in higher total costs of direct box filling in this comparison. On the other hand, the better quality of tubers can achieve a higher price on the market.

The used 4-tons boxes are very large. Mostly the farmers operate with smaller boxes. Therefore, the development of a device for filling of two smaller boxes simultaneously has been started last year.

After three years it is estimated that the device for filling and transfer of storage boxes on the harvester is favourable for the farmer. The new filling method is especially recommended for sensitive varieties and for premium potatoes.

7. ACKNOWLEDGMENT

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