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Susceptibility to mechanical damage of potatoes cultivated in different environmental conditions**,***

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A b s t r a c t. Seven potato varieties were cultivated in 12 localities that can be classified into two characteristic regions: i) classical higher land region (cooler and more humid) and ii) lower land region (warmer and drier), in the years 1995-1997. Susceptibility to mechanical damage of the harvested tubers was studied extensively using the pendulum MIDAS 88 PP. The obtained parameter, so called 'Pendulum index' (PI), represents percent share of the tubers not damaged in the test. The obtained results show that season, region and variety significantly influence the pendulum index. PI of the tubers produced in the lower land region was significantly higher (~74 %) in comparison to the higher land region (~61 %). The season played the main role in the obtained PI values: 87 % (1995), 53 % (1996) and 64 % (1997). The analysis of weather conditions shows that tuber susceptibility to mechanical damage is reduced by slightly higher than normal rainfall during the entire growing period. This relation becomes even more evident with rainfall at the end of the vegetation period (total rainfall in August and September of about 150 mm) and, at the same time, under slightly higher than normal temperature at the end of vegetation period. Weather variations and extremes have to lead to increasing potato damage.

K e y w o r d s: potatoes, mechanical damage, pendulum index, locality, season

INTRODUCTION

Damage to potato tubers due to mechanical forces is among the most important causes of loss of production and quality reported throughout the world. The causes of such damage are mechanical injuries that occur primarily in association with harvesting and grading (Peters *et al*., 1996). Apart from the losses incurred due to rejected tubers, additional losses to the producer result from the higher labour cost of sorting out damaged tubers and increased wastage in store due to increased moisture loss, and to the higher incidence of secondary infections (Gray and Hughes, 1978).

In the Czech Republic, a considerable part of the soils *ie* light-medium under perfect climatic conditions of the Bohemia-Moravian Highland, have a higher content of stones in the top soil (10-40 t ha^{-1}). The stone amount in the soil has caused significant tubers damage during harvest, transport, adaptation and storage, caused by mutual contact of clods and stones (Fér *et al*., 2004).

The damage which occurs can be divided into two groups – firstly, external damage including scuffing on the skin, cuts or gouges, crushing and splits or cracking, and secondly, internal damage which is usually of two types: internal shattering or cracking and blackspot (Storey and Davies, 1992). Mentioned forms of mechanical damage such as shattering and crushing (Baritelle *et al*., 2000) can be important, playing different roles in relation to different varieties and/or cultivation regimes. Gray and Hughes (1978) showed that the forms of damage are affected by variety, maturity, and growing and storage conditions. The amount of damage due to mechanical forces depends on mechanical and rheological properties of tubers that are generally termed as susceptibility to damage. These properties interrelate with the modifying environmental influences (Storey and Davies, 1992), so that also the size and shape of tuber influence the amount of damage occurring. With

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regard to shape, tubers having a small radius of curvature, for example long tubers are more prone to damage, perhaps through a more limited contact area. On the other hand, tubers of a large radius impacting each others produce less damage (Carruthers, 1982). Cultivars with weak skins are often more susceptible to cracking (Storey and Davies, 1992). Muir and Bowen (1994) examined the effect of three methods of haulm destruction on skin strength and structure. Results of their experiments showed that none of the skin characteristics was related to a stronger skin except in the case of cultivar Record were the strength of the skin was always related to its thickness. The second experiment revealed that only 25% of tubers showed signs of scuffing damage after pulling, compared to 33.6% after chemical desiccation with Diquat and 37.6% after flailing. The skin strength is associated with maturity of tuber (Burton, 1989; Sowa-Niedzialkowska, 2000). Zdunek and Konstankiewicz (2004) used a method of passive acoustic emission (AE) to investigate the micro-cracking processes in compressed plant tissue. Compression tests with simultaneous recording of the AE signal were carried out on cylindrical samples of potato tubers at various strain rates and turgor. The AE signal was detected before sample failure. The stress and strain at the moment of the first AE signal are called critical stress and critical strain. An increase in the strain rate and/or turgor decreases critical stress and critical strain. A comparison of the experimental results with a mechanical model of a single plant cell has shown that cracking of cell walls is the source of the AE signal in compressed plant tissue.

The variety-dependent susceptibility of potatoes to serious mechanical injury was confirmed in three-year experiments (Misener and Tai, 1993), which was also confirmed by other authors (Gall *et al.*, 1996; Sowa-Niedzialkowska, 2000). The precise reasons why certain varieties are more predisposed to external damage are unclear. The cultivar responses can be modified by growing conditions and mineral nutrition; both affect specific gravity and perhaps cell wall structure and cell size. Higher values of specific gravity generally show higher bruising (Gray and Hughes, 1978). Bruises are usually classified as a special type of mechanical damage (Baritelle *et al.*, 2000) termed also as black-spot bruises that: '... have no visible cell wall or cell debonding damage although the cells are often damaged. Typically, recent bruises are blue black and in perimedulary tissue rather than in cortex. Dislocation appears within 48 h at 10-20°C. Black-spot occurs in warmer more flaccid tubers, especially if potassium is deficient; and is associated with lower damaging drop heights (lower impact velocities)'. These conclusions are in agreement with Molema's study (1999). Field damage has been proved to be affected by site, season, fertilizers and cultural practises. It is not clear whether this is a direct effect of smaller cells giving a greater surface area per unit volume of tissue and greater strength, or whether it reflects differences in cell wall composition between small and large cells. It has often been shown that also soil conditions affect damage. Rainfall and irrigation have been found to increase damage. Generally, cultural conditions which reduce the turgor or firmness of the tuber, such as root cutting and cessation of irrigation well in advance of harvesting, reduce susceptibility to mechanical damage (Gray and Hughes, 1978). Konstankiewicz and Zdunek (2001) investigated the influence of turgor and cell size on the process of potato tissue cracking. Results of their experiments showed that increase in turgor caused a decrease in the compressive strength, critical strain and stress. Higher contributions of smaller cells cause an increase of the compressive strength, but smaller resistance to micro-damage.

The effect of rainfall and temperature distribution during the growing season on the degree of mechanical damage to potato tubers was studied in Poland. The index of mechanical damage was positively correlated with rainfall in May - September, more particularly during August - September, and negatively correlated with the heat sum in May - September, more particularly during ripening (Marks *et al.*, 1993). Susceptibility to mechanical damage is reduced in seasons with drier and warmer weather, especially at the end of vegetation period (Sowa-Niedzialkowska, 2000). Some authors (Storey and Davies, 1992) showed that susceptibility to external damage is also affected by chemical composition of tubers, especially dry mass content. Blahovec *et al.* (1990) found that resistance of tubers to mechanical damage decreased not only with increasing dry mass content in the tubers but also with increasing fibre content of tuber sides.

Many attempts at finding some correlation between parameters of quasi-static tests (puncture tests, compression tests etc.) and susceptibility to mechanical damage in 1950s and 1960s ended without success. This is why the dynamic tests have been used to determine the potato susceptibility to mechanical damage (Hamouz *et al.*, 2004). Pendulum test (Skrobacki *et al.*, 1989) with appropriate instrumentation provides information on impact parameters, such as energy absorbed, tuber tissue deformation and impact duration, which enable more precise relationships to be established between the tuber characteristics and type and extent of damage. Extensive knowledge of the instrumented device and indications on the bruise susceptibility of a product are two indispensable conditions for successful damage prevention and reduction. As data acquisition techniques become more sophisticated and the autonomy of the measurement equipment tends to be better, the new generation of electronic potatoes, such as the Danish made PTR 200, seems promising for bruise prevention purposes. This is mainly due to improved memory capacity and more accurate data acquisition techniques (Van Canneyt, 2003). The instrumented devices (PMS 60, IS 100, PTR 100 *etc.*) are sufficiently equipped and frequently applied to locate those zones in the harvesting and processing chain that present a high level of risk of damage (Baheri, 1997).

The aim of this paper is to demonstrate the differences in susceptibility to mechanical damage among the potatoes cultivated in different environmental conditions of three seasons and two different production regions of the Czech Republic.

MATERIAL AND METHODS

Potato samples

The varieties Impala, Karin, Agria, Korela, Rosella, Santé and Ornella were cultivated in field trials according to unique farming techniques at twelve localities in the Czech Republic during the years 1995-1997. Six of the twelve localities were situated in lower, warmer and drier regions (average above sea level 244 m) with fertile, predominantly loam soils (prevail Orthic Luvisol and black Luvic Chernozem). In this contribution, they are indicated with common term ‘lower regions’. Other localities were situated in higher (average above sea level 531 m), cooler and more humid regions with less fertile, predominantly sandy loam soils (prevails Cambisol). They represent traditional potato growing regions in the Czech Republic. In our contribution, we have indicated them as ‘higher regions’. The mean main weather parameters in the tested period are presented in Table 1. The tubers of the mentioned varieties were manually harvested and healed three weeks at 15°C and 95% humidity.

Pendulum test

Perfect 30 tubers, 40-60 mm in diameter, were used in the test. The pendulum Midas 88PP (Dr. Ing. H. Gall - Sensorik, Gross Lsewitz, Germany) was used as a tester of susceptibility of the tubers to mechanical damage. Every tuber was tested in a special jig (Gall and Zachow, 1992) and then impacted two times repeatedly into the same side part of the tuber by the pendulum impactor (m = 0.048 kg, impact energy E_0 = 150 mJ, diameter of indentor = 7 mm). The rebound heights after impacts were determined and the individual test was classified as ‘elastic’ when the second rebound height was higher or equal to the first one. The pendulum index (PI) for the whole sample was calculated as the sum of the elastic impacts divided by the total number of the tested tubers (30).

Statistics: SAS 6.12 package was used for statistical evaluation of the obtained results.

RESULTS AND DISCUSSION

The obtained results are presented in Figs 1-5. The results show that the pendulum index, as a measure of susceptibility to mechanical damage, is strongly influenced by region, variety and year, but the role of these sources of variance is different according to each source (F - values for all of the measured pendulum indexes for the regions were 49.85, for the varieties – 18.28, and for the years – 134.07).

T a b l e 1. Main weather characteristics of the regions in 1995-97

Year	Region	Average temperature (°C)			Sum of precipitation (mm)		
		August	September	April-Sept.	August	September	April-Sept.
1995	LR	18.92	13.57	15.63	90.6	82.4	439.9
	HR	16.15	11.80	13.42	100.2	113.0	527.7
	Average	17.53	12.68	14.53	95.4	97.7	483.8
1996	LR	18.23	11.10	14.57	73.3	53.1	463.5
	HR	16.12	9.02	12.40	97.1	69.0	490.9
	Average	17.18	10.06	13.48	85.2	61.1	477.2
1997	LR	19.90	13.98	15.02	46.9	29.3	391.8
	HR	18.02	12.70	13.12	33.6	25.6	487.9
	Average	18.96	13.34	14.07	40.2	27.3	439.8
Long-term average	LR	18.03	14.28	15.15	71.5	45.4	360.1
	HR	15.83	11.23	12.73	83.2	52.2	424.7
	TA	16.93	12.76	13.94	77.3	48.8	392.4

LR - lower regions (average of 6 localities), HR - higher regions (average of 6 localities), TA - total average of all 12 localities.

Role of region

The obtained results show clearly differences between the two studied types of regions. For potatoes cultivated in lower land regions significantly higher values of PI were measured than in higher land regions. This conclusion can be made not only for total sum of experiments but also for the individual seasons separately. The results represent 7 varieties and 6 localities for every region type in every year are shown in Fig. 1. We suppose that these clear results have to be connected with the level of maturity of the harvested tubers, thickness of tuber skin, and maybe also the tissue cell dimensions (Burton, 1989; Konstankiewicz and Zdunek, 2001; Sowa-Niedzialkowska, 2000; Wirsing and Horneburg, 1994). Long-time experience shows (Gray and Hughes, 1978) that in higher land regions the level of maturity is lower than in lower land regions, because lower temperatures in those regions extend the vegetation period (Hamouz *et al*., 2004). In our case, similar conditions were also observed (Table 1). In all the seasons, lower temperatures were measured in comparison to the lower land regions. On the other hand, precipitation sums were higher in the higher land regions than in the lower ones; the same conclusion can be made for precipitation sums in August - September period, in which potatoes matured.

Role of variety

Significant role of variety for PI- value seems to be the lowest among the analysed samples. It is shown for 12 localities and 3 years in Fig. 2. The role of variety in susceptibility to mechanical damage was studied by many authors (Baritelle *et al*., 2004; Gall *et al*., 1996; Misener and Tai, 1993; Muir and Bowen, 1994; Wirsing and Horneburg,

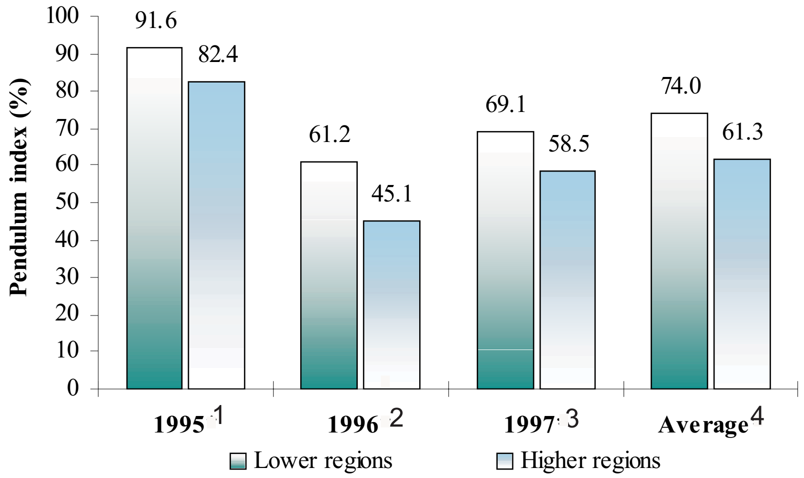

Fig. 1. Pendulum index of potatoes cultivated in different conditions. LSD (Tukey's test): 1 - 5.08, 2 - 6.77, 3 - 5.58 and 4 - 3.35.

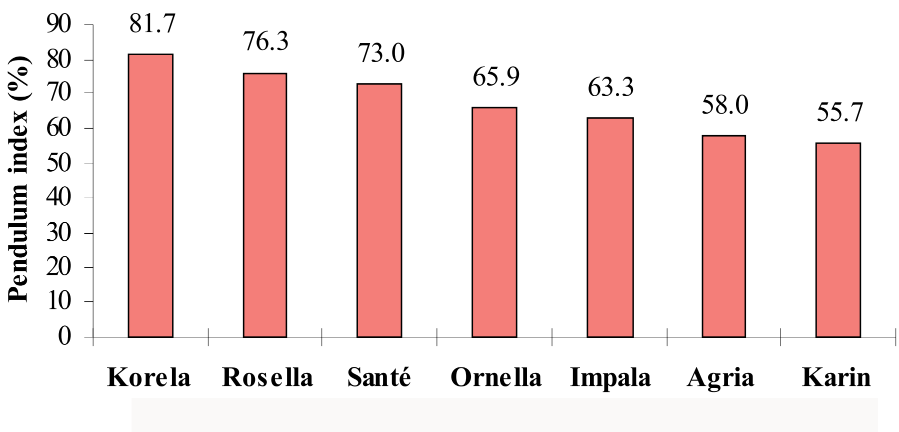

Fig. 2. Pendulum index determined for different varieties of potatoes. LSD (Tukey's test) – 9.47.

1994) and our results confirm the previous studies. From seven varieties used in the experiment, the highest values of PI were observed for medium-early varieties Korela, Rosella and Santé; these values were significantly higher than values found for early varieties Karin, Agria and very early variety Impala. For medium-late variety Ornella, the medium values of PI were observed. The PI differences observed for different groups of varieties can be caused by the differences in DM content (Blahovec *et al*., 1990; Storey and Davies, 1992), which correlates at least partly with the length of the vegetation period (Storey and Davies, 1992). This way of interpretation of our results finished without success. It seems that variety disposition to mechanical damage is modified by the ecological and cultivation conditions in a way that is very difficult to define (Misener and Tai, 1993; Muir and Bowen, 1994).

Role of season

The F-test values show that season played the main role as a source of variance in our results. Different years are distinct by significantly different values of PI as it is shown for 7 varieties and 12 localities in every year in Fig. 3. The lowest season PI-value was observed in 1996 (83.4% of PI-value in 1997 and only 60.9% of PI-value in 1995). This relation can be caused by lower maturity (Sowa-Niedzialkowska, 2000; Burton, 1989; Wirsing and Horneburg, 1994) of tubers in 1996, in which the lowest mean air temperature in the vegetation period was observed (0.5°C

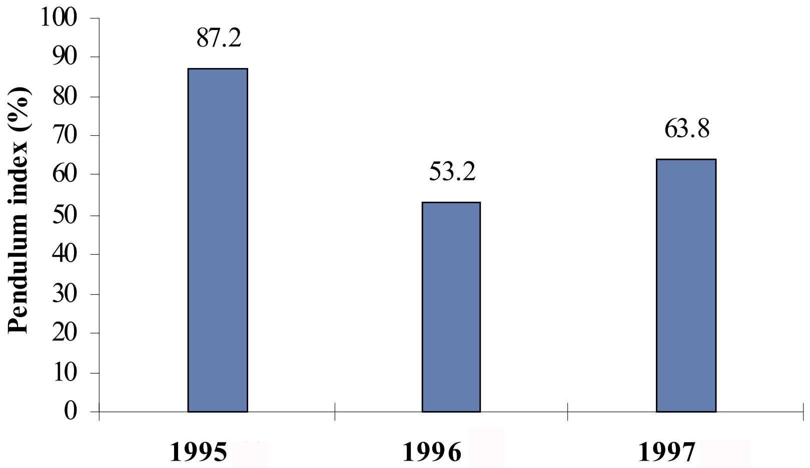

Fig. 3. Pendulum indexes determined for potatoes cultivated in different years. LSD (Tukey's test) – 4.92.

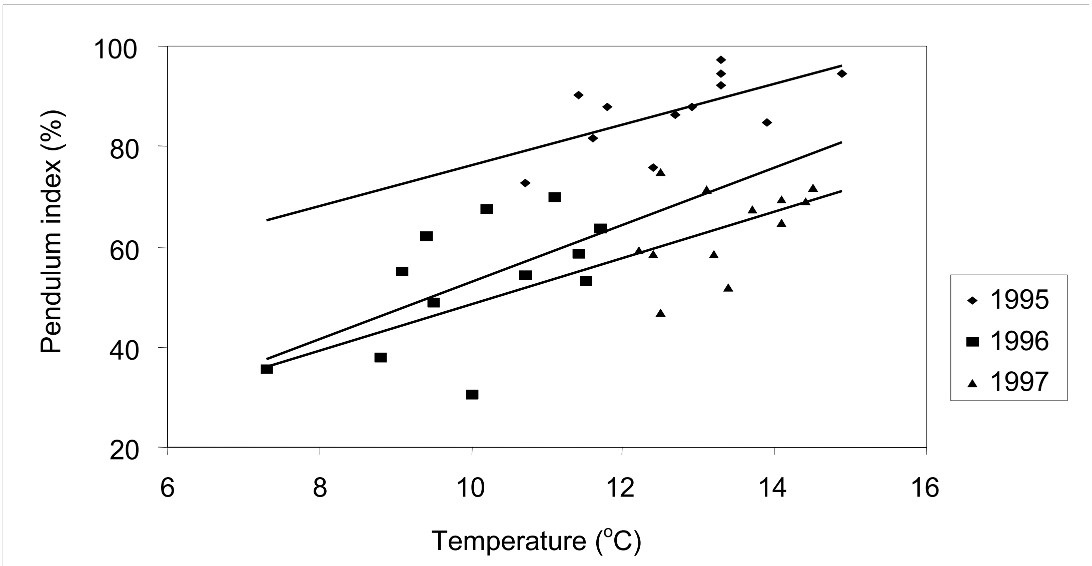

Fig. 4. Relationship between pendulum index and average air temperature of September in different places.

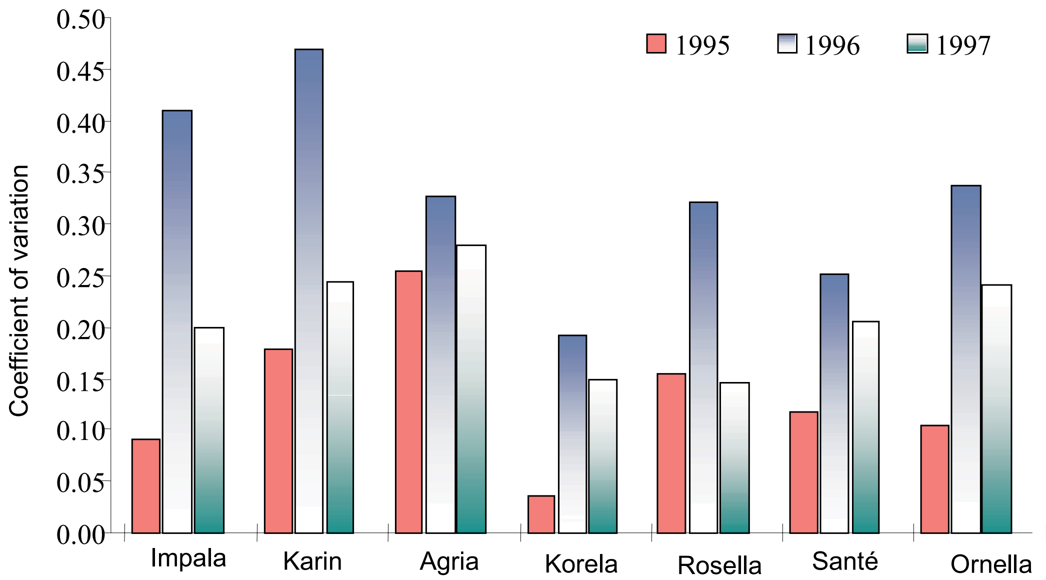

Fig. 5. Coefficient of variation of pendulum indexes for variety sets in single year.

below the long-time mean value). Especially September 1996 was extremely cold with mean temperature 2.7°C below the long-time mean value. In all the years, PI increased with the increasing average air temperature in September (Fig. 4), but in 1996 this trend was the most evident and was connected with cold weather in that month.

The precipitation level in the vegetation period in 1996 reached 121.6% of the long-time mean value; in August it was 110.2% and in September even 125.2%. Similar weather is mentioned also by Marks *et al*. (1993) as weather increasing susceptibility to mechanical damage. Also the dry mass content of the tubers was the lowest in 1996. In 1997, with very hot and dry weather at the end of the vegetation period (Table 1), higher values of PI were observed than those in 1996. The best influence on the sensitivity to mechanical damage was observed in 1995 *ie* in the year with slightly above-mean temperatures and precipitation during the whole period of vegetation. Similar trend was also observed for coefficient of variation (CV). The CV for the single variety and season sets is presented in Fig. 5. It is clear that high CVvalues in Fig. 5 correspond to low values of PI plotted in Fig. 3. It means that in the season with worse weather conditions (1996) not only lower values of PI, but also higher CV of this parameter were observed. In agreement with other authors (Gray and Hughes, 1978), our results show that the susceptibility to mechanical damage can be reduced, especially in seasons with medium and stable weather. Weather variations and extremes have to lead to increased potato damage and increased yield losses.

CONCLUSIONS

1. The obtained results show that susceptibility of potatoes to mechanical damage is significantly influenced by region, weather and variety.

2. Lower regions of the Czech Republic posses better conditions for production of potatoes with low susceptibility to mechanical damage when compared to higher regions (probably due to superior tuber maturity).

3. Influence of variety on susceptibility to mechanical damage was the lowest among the factors in question. Significantly higher pendulum index was noticed for medium-early varieties Korela, Rosella and Santé in comparison with early varieties Karin, Agria and very early variety Impala.

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