Growth Dynamics and Occurrence of Cracks in Kohlrabi Tubers (*Brassica oleracea* var. *Gongylodes L.*)

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Abstract

The long-term influence of growth patterns on the occurrence of tuber cracks of kohlrabi (*Brassica oleracea* var. *gongylodes* L.) was evaluated based on the Goudriaan-Monteith expolinear model. Its three main fitting parameters are maximum relative growth rate (r_m), maximum absolute growth rate (c_m) and 'lost time' (X intercept of the linear growth phase, t_b). Only the long-term pattern t_b was found to be related to the occurrence of tuber cracks, when comparing different planting dates. Therefore, the influence of environmental factors was linked to the occurrence of tuber cracks by the 'lost time' (t_b). This suggests that the earlier the beginning of the linear phase, the higher the risk of tuber cracking.

INTRODUCTION

Cracking of kohlrabi (*Brassica oleracea* var. *gongylodes*) tubers is a serious problem, occasionally affecting up to 80 % of this crop (Fölster, 1991; Lippert, 1997). Therefore, the objective of these studies was to examine the effects of climatic as well as endogenous growth factors on cracking of kohlrabi tubers, whereas this contribution is focussed on growth characteristics as an endogenous factor influencing tuber cracking.

MATERIALS AND METHODS

Plant Material

Two kohlrabi (*Brassica oleracea* var. *gongylodes*) cultivars were used for the field trials, cv. 'Express Forcer' as cracking susceptible and cv. 'Noriko' as cracking resistant. Kohlrabi seeds were germinated in an organic substrate in trays and seedlings transferred 2-4 weeks after germination into the open field and planted at a density of 16 plants m^{-2}.

Cultivation

The field experiments were conducted on a sandy loam at the Research Station of the University of Stuttgart-Hohenheim, Germany. Planting dates of subsequent experiments during each year differed about two weeks. Therefore, the season started with the first planting date at the end of March (experiment 1) and ended with the tenth planting date in September (experiment 10). Prior to planting, the plots were fertilized with P, K and Mg. According to soil analysis N-fertilization was restricted to 180 kg N/ha. To avoid soil water stress irrigation was applied whenever soil water potential was below -120 mbar, measured by tensiometers in different sites of the experimental area.

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Data Acquisition

Ten experiments were conducted during the vegetation period each year during two years. For the single experiment, four replicates of 125 plants each were used. The occurrence of cracked tubers was observed daily in conjunction with tuber diameters. Affected kohlrabi plants were labeled to avoid multiple counts. Within the same experiments, the diameters of four randomly selected intact tubers of each replicate were measured daily to obtain the difference in diameter between intact and cracked tubers. Daily observed diameters of cracked and not cracked tubers could be calculated as function of time. Expolinear model (Goudriaan and Monteith, 1990) was fitted to tuber growth data of cracked as well as intact kohlrabi tubers (Fig. 1). The Ghoudriaan-Monteith expolinear equation is:

$$W = (c_m / r_m) \ln (1 + \exp(r_m (t - t_b)) \qquad \text{Equation (1)}$$

where W= plant (tuber) weight, C_m = maximum absolute growth rate (in weight gain reached in the linear phase), R_m = maximum relative growth rate (in weight gain per unit weight per day), t = time in days, t_b = x-axis intercept of the linear growth phase (termed the "lost time"). The model was fitted to data of tuber growth using non linear regression procedure of SPSS statisic program (SPSS inc.).

RESULTS AND DISCUSSION

There was only weak correlation between relative growth rates (RGR) and incidence of cracked tubers (unpublished data). To evaluate a more distinct relationship between growth characteristics and cracking of kohlrabi tubers, we used non linear regression method based on expolinear model as described above. Through this model, three parameters were fitted delivering information about growth dynamics as described (Equation 1). The expolinear regression parameters showed that the cracked and not cracked kohlrabi tubers had similar maximum relative growth rates (r_m) and linear growth rates (c_m), but 'the lost times' differed in most cases (Table 1). Growth curves of cracked tubers showed smaller t_b than those of unaffected ones resulting in an overall faster tuber growth. This can be confirmed in correlating t_b of unaffected tuber growth with the amount of cracked tubers within each experiment (n = 40 per year and cultivar). Figure 2 shows the correlation between t_b (lost time) and occurrence of cracked tuber on the data based on over the season repeated field experiments and the cultivar 'Express Forcer'. Growth curves of cracked tubers had lower t_b than those of unaffected ones. The consequence for the shape of growth curves is illustrated in Fig. 1. Negative correlation between t_b and occurrence of cracks has to be interpreted on the base of Goudriaan' and Monteith's (1990) definition. The authors defined t_b as a function of initial fresh weight (F_0) and relative growth rate (r_m) as it shown in equation (2):

$$t_b = - \ln(F_0 / (1-F_0))/R_m \qquad \text{Equation (2)}$$

Whereas, expolinear growth function is developed for emerging crops, we assume that equation (2) is valuable also for plant stands. Since no correlation between r_m and occurrence of cracks (Table 2) occurred, t_b should depend on F_0. This suggests that in the case of planted kohlrabi, that the risk for occurrence of tuber cracks will be established in the very early phase of rising transplants, which is in accordance to observations made on radish. Bleyaert (1990) reported that different cultivars of small radish (*Raphanus sativus* var. *radicula*) that the longer the period of emergence is, the higher the risk for tuber cracks. Therefore, we will focus in further investigations on the influence of transplant quality on the subsequent development of tuber cracks in kohlrabi. Special emphasis will be placed on the phase of cell differentiation and subsequent cell elongation in different tuber tissues. Based on research of Edelmann (1995) in *Heliantus annuum*, the epidermal tissue of sprouts is characterized without elastic cell walls. Hence, the expansion of inner tissues in kohlrabi tubers like parenchyma with extremely elastic cell walls are inhibited

during growth by its surrounding stiffer epidermal tissue (Lippert, 2000). This causes tensions, which occasionally will lead to open tuber cracks (Oyanagi et al., 1987). Therefore, we will examine the climatic influence in very early developmental stages of tuber growth on its cracking susceptibility.

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Tables

Table 1. Maximum growth rates within the linear phase of kohrabi tuber development c_m [g day^{-1}] with (+) and without (-) cracking symtoms (cv.Express Forcer), means of 4 replicates

year	symptom	experiment[1]									
		1	2	3	4	5	6	7	8	9	10
1994	–	20.77 ±4.8	12.14 ±3.1	19.79 ±4.1	18.48 ±7.3	48.58 ±6.5	19.85 ±6.6	7.07 ±1.7	11.02 ±1.4	18.91 ±5.7	12.55 ±3.2
	+	48.58 ±10.2	k..	25.81 ±5.5	73.27 ±14.9	60.53 ±12.7	16.41 ±7.7	10.88 ±1.9	22.24 ±2.4	36.52 ±4.3	7.65 ±0.9
1995	–	24.03 ±4.4	46.13 ±6.1	40.45 ±8.9	69.11 ±11.3	43.96 ±7.8	34.35 ±5.3	18.34 ±6.2	28.91 ±7.4	27.43 ±7.1	11.09 ±1.5
	+	33.12 ±8.5	47.77 ±9.6	41.84 ±11.3	77.2 ±12.8	58.55 ±14.5	40.41 ±12.2	15.34 ±3.3	39.12 ±5.5	41.22 ±28.4	14.64 ±2.0

[1]subsequent experiments during the season beginning in March ending in Sept.

Table 2. Maximum relative growth rates of kohrabi tuber development r_m [g day^{-1}] with (+) and without (-) cracking symtoms (cv.Express Forcer), means of 4 replicates

Year	symptom	experiment[1]									
		1	2	3	4	5	6	7	8	9	10
1994	–	0.22 ±0.06	0.31 ±0.08	0.40 ±0.10	0.23 ±0.07	0.28 ±0.09	0.41 ±0.11	0.61 ±0.06	1.41 ±0.11	0.16 ±0.01	0.18 ±0.07
	+	0.15 ±0.04 a	k.A.	0.24 ±0.11	0.17 ±0.09	0.51 ±0.12	0.13 ±0.06	0.87 ±0.13	0.16 ±0.04	0.79 ±0.21	0.48 ±0.05
1995	–	0.16 ±0.01	0.54 ±0.11	0.21 ±0.06	0.22 ±0.08	0.35 ±0.12	0.16 ±0.06	0.24 ±0.05	0.28 ±0.08	0.13 ±0.07	0.13 ±0.09
	+	0.22 ±0.05	0.32 ±0.07	0.55 ±0.03	0.48 ±0.07	0.31 ±0.12	0.29 ±0.09	0.17 ±0.03	0.41 ±0.11	0.22 ±0.14	0.14 ±0.10

Figures

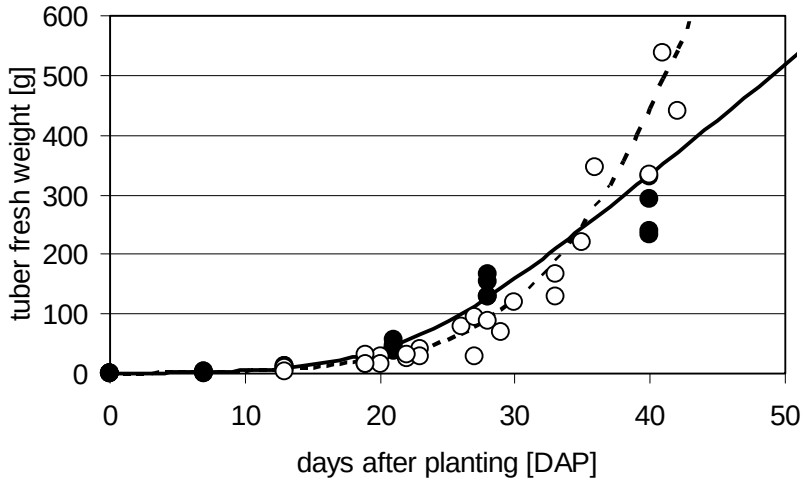

Fig.1. Example for expoliner growth curve fitting of cracked (open symbols) and not cracked (filled symbols) kohlrabi tubers (cv.'Express Forcer')

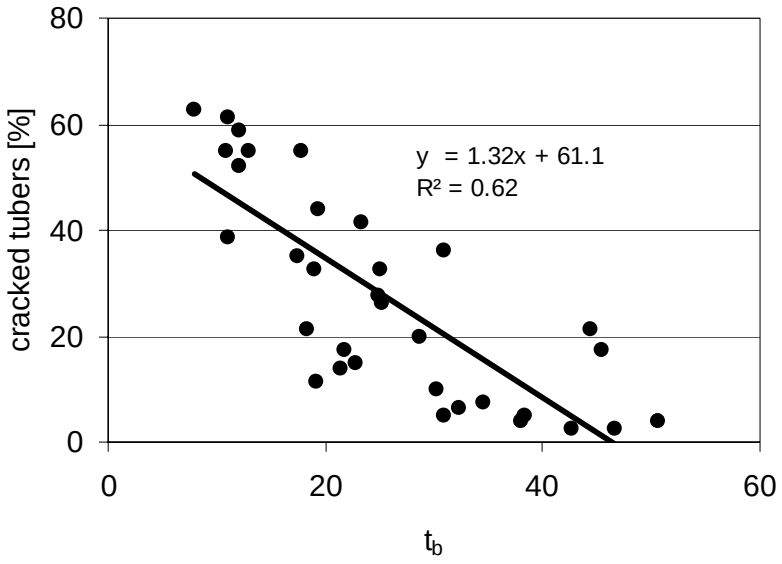

Fig. 2. Correlation between t_b and amount of cracked tubers (means of 20 field experiments with 4 replicates, cv.‘Express Forcer‘)