INFLUENCE OF CLIMATIC CONDITIONS ON CRUMBLY FRUIT in RASPBERRY (RUBUS IDAEUS L.)

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INTRODUCTION

Crumbliness of red raspberry fruit is well known worldwide for a long time (Daubeny, 1967). Whenever a virus, especially the raspberry bushy dwarf virus, can be found by testings the reason for crumbliness is obvious.
However in many cases even repeated thorough testing gave no information on virusinfection. Since the early 1990ies the amount of crumbly fruit increased especially in Germany and France. The phenomenon is well known on farms.

There are some hypotheses for the cause of crumbliness

1. in vitro propagation
2. climatic conditions

1. There are indeed some aspects supporting this hypothesis. We realize this problem since the beginning of the 1990s. A few years earlier commercial in-vitro propagation of raspberries had started, so one may assume a fair amount of in-vitro propagated plants to be on farms. Also from this time on growers are looking for alternative cultures. Small fruit and especially raspberry plantations increased in Germany. Therefore more plants were ordered, which had to be propagated conventionally or in-vitro. In one season about 25 descendants can be obtained from one mother plant by root cuttings (Licht, 2005**).** Depending on the number of subcultures much more descendants (about 2000) may be obtained from the tissue of a mother plant by in-vitro propagation (Lankes, 2005).

2. The percentage of crumbliness in a plantation differs within the years. At the research station in Weinsberg one of the raspberry-plantations was grown under permanent raincover. This shelter increased temperature in average by 1°C, on days with high radiation even up to 10°C. No correlation between crumbliness and increased temperature under plastic cover was found in comparison to plants grown in open field. But crumbly fruit were found in both variants. This yearly variation of crumbliness could not be explained by the above trial, so a trial was started within the COST action 836 at many European research stations.

MATERIAL AND METHODS

design of the trial

planting date:	spring 2002 (German plants: March, French plants: April)
observation period:	2003- 2004/5
planting system:	planting on raised beds 0,5 m x 3,0 m - 3,5 m variable V-system
plants per plot:	10
number of replications:	3
number of plants per variant:	30

variants:

1 `Meeker`, origin Kraege nursery, Germany, conventional propagation
2 `Meeker`, origin La Fond nursery, France; in vitro propagation
3 `Tulameen`, origin Kraege nursery, Germany, conventional propagation

On at least 5 picking days each year the yield and the amount of crumbly fruit and also the weight of marketable fruit were recorded. To describe the vigour of the plantations in the first year the length of the canes was measured.

The cultural technique applied was as usually practised at each station. Soil data and weather data were recorded.

The participants were: Station d' Expérimentation Fruits Rhône-Alpes (SEFRA), Etoile France-; Unité d'amélioration des Espèces Fruitieres et Ornamentales (INRA), Beaucouzé Cedey, France-; Praktijkonderzoek Plant en Omgeving - sectie fruit, Randwijk, Nederland-; Area de Cultivos Hortofruticolas y Forestales, Villaviciosa, Asturias, Spain-; ADAS, Manor Farm, Oxford, United Kingdom-; Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg, Germany.

The results were not put into any statistical analysis because of various reasons. The structure of the reported data varied. Furthermore the amount of crumbly fruit in this observation period was very low. Also, in each variant the amount of crumbliness differed among the plots. Some data were transferred to logarithm to equalize the random distribution of crumbliness. No more information could be obtained from this analysis; therefore datas are not shown in this report.

Soil and climatic data of the trial sites

The research station Weinsberg, Germany is situated about 200 m above sea level. The soil is a luvisol, derived from loess with good water capacity and a pH of 6.2 (table 1). The long-term average temperature is 9.5°C and the long term annual rainfall is 630 mm. During the years 2003 until 2005 it was warmer and there was less rainfall. Spring frosts in April and/or May occurred through all years.

The average temperature at the research station in Villaviciosa, Spain (table 2) is higher with 14,2°C, as well as 13,6°C in 2004 compared to the other trial sites. There was also a high amount of rainfall during the years. The average temperature never dropped below 0°C

throughout the year and did not increase in maximum above 25°C, indicating a very balanced climate. The soil is medium with a pH of 7.3.

At Manor Farm, Oxford, United Kingdom, they had spring frosts in 2004 and 2005, but plants and fruit were not severely injured.

The trial site in Beaucouzé, France may be characterized as following: a soil with high clay content and sand with a very high pH (8.2). The yearly rainfall differs in the years 2003 till 2005 enormously. There were 809 mm found in 2003 and only 306 mm in 2005. The average temperature was found to be in between 12°C and 13°C (table 2). There were no temperatures below 0°C and no maximum temperatures above 30°C in these years**.** Temperatures are moderate with little rainfall.

The soil of the research station Rhône-Alpes in Etoile, France consists of 19 % clay and 54 % sand and 13 % silt and has a pH of 7.1 (KCl) (table 1). Weather data show that the average monthly temperature does not fall below 0°C. With 14°C the average temperature in 2003 was higher compared to 12,8°C in 2004. Maximum temperature reached 35°C in summer 2003 and 30°C in 2004. It rained about 900 mm in both years.

In Randwijk, Netherlands the soil of the trial site is river clay with a clay content of 20 %. The pH is 7.5. The average temperature in winter stays above 0°C but can fall to minus degrees on some days. Yearly average temperature is about 10°C. Maximum summer temperatures can be up to 35°C.

Especially the year 2003 may be characterized as very warm with temperature maxima up to 40°C on some days and too dry all over Europe.

Description of a crumbly fruit

A crumbly fruit has a reduced number of drupelets in comparison to a normally developed fruit (picture 1). These drupelets may be swollen. At maturity time these fruits crumble while picking because of a weak cohesion. Crumbly fruit may be spread in the plantation. A few fruits on some canes may be affected or entire canes can bear crumbly fruit only (these are called “crumbly canes”). These fruits are neither suitable for fresh market nor for freezing. There are no symptoms on vegetative organs indicating crumbliness.

RESULTS
Crumbliness

1. **Germany, research station Weinsberg**

The plants of all variants grew very well so that the plantation was vigorous. Visually the plants were healthy and did not show any virus infection.

Also the yield of the seasons 2003 until 2005 was satisfying. With 2% to 3% the average amount of crumbliness was generally low in 2003 and 2004. Looking more closely at the replicants differences among the plots can be seen (table 3). One variant among the `Meeker` (Germany) plots shows some more crumbly fruit in 2003 and 2004. In the French `Meeker`-plots, there is one plot with some more crumbliness in each year but it is not the same replicant in both years. In addition one of the `Tulameen` replicants shows some more crumbliness than in the other two plots.

In 2005 the number of canes bearing only crumbly fruit (crumbly canes) was recorded. These figures confirm one plot with `Meeker`, K., Germany plants to have more crumbly fruit than the other two replicants. Crumbly canes lead to more crumbly fruit in all years. The character 'crumbliness' seems to be distributed randomly which makes a statistical analysis impossible.

The average of all `Meeker` plots of both variants indicate less than 5 % crumbliness in both years. About the same percentage of crumbly fruit in `Meeker` Germany and France can be found during all years. There is no difference between the two `Meeker` origins looking at the average. Data of a further `Meeker` variant are shown. These `Meeker` plants were produced by tissue culture at the nursery in Oberdorla, Germany. The amount of crumbly fruit was also low. `Tulameen` plants seem to have less crumbly fruit than `Meeker` plants.

2. **Spain, research station, Villaviciosa**

Cane growth and habit of the plants as well as the yield of all plots was good. The yield is increasing from the year 2003 to 2004. The percentage of crumbly fruit was extremely low during the observation period. In all replicants of each variant the percentage of crumbly fruit was less than 1 % (table 4). There was no difference between `Meeker` and `Tulameen` plots.

3. **Great Britain, Manor Farm, Oxford**

The plants were vigorous and the recorded yield was good. There are no data of 2003, but of the years 2004 and 2005. The figures were taken from one replication. In both years no crumbly fruit were found (table 5). Especially the fruit quality of `Tulameen` was reported to be very good.

4. **France, research station, Beaucouzé**

The canes were healthy and vigorous but were only about 150cm long, perhaps because there was no irrigation provided. There were problems with a loss of fruit, so the yield was very low.

Concerning the amount of crumbly fruit some differences could be observed. There was no crumbliness found in all replicants of `Meeker`, K. Germany plots in all years (table 6**).** In 2003 only very few crumbly fruit occured in plots with `Meeker` plants of the origin France. But in 2004 more crumbly fruit were found in two replicants of this variant. In the year 2005 again the amount of crumbliness was very low. The distribution is therefore confusing. In general, the amount of crumbliness in `Tulameen` plots is very low. Only in 2004 some more crumbly fruit were found in one replicant.

5. **France, research station Etoile, Rhône-Alpes**

The canes showed full growth and a good vigour. There are no data about the yield , but in 2003 and 2004 "crumbly canes" were counted. Some "crumbly canes" could be found in more or less all plots. Table 7 shows, that in plots of the variant `Meeker`, K. Germany, in 2003 one of the replicants had some more "crumbly canes" than the other two replicants. In the year 2004 the percentage of "crumbly canes" increased. So in average of the three replicants there were more crumbly canes found in 2004 than in 2003. Among the plots of the variant `Meeker` France in both years one of the replicants showed some more "crumbly canes". Another replicant was observed with less than 1 % crumbly canes in both years. Two `Tulameen` variants were used in this trial. The German `Tulameen` showed less crumbly canes than the French `Tulameen` plants. Again we saw one plot with very few "crumbly canes" in both years and another one with some more "crumbly canes". Among the French `Tulameen` plots we found two plots with some more "crumbly canes" in both years.

6. **The Netherlands, research station, Randwijk**

The plants were grown under permanent rain cover and supplied with ferti-irrigation. The canes were vigorous and showed a length of about 180 cm. The yield was good. Six canes were observed in 2003. The percentage of crumbly fruit ranged between 1,4 % and 2,3 % and was very low in all three variants (table 8).

DISCUSSION

The red raspberry (Rubus idaeus L.) is supposed to be a plant of the sparse forest. This indicates the demands on optimal growing sites. The raspberry plant likes a soil with good water capacity and drainage and enough air volume. The site should be light and protected from strong winds. Raspberry plants prefer sites with moderate temperatures and sufficient humidity. So growing areas such as the pacific Northwest of the USA are traditionally preferred (Daubeny, 1971), because of a moderate climate with temperatures seldomly dropping below 0°C (Crandall, et al., 1974).

Raspberry plants respond to a growing site that is not satisfying**.** The reaction may be a loss of yield, crumbly fruit or reduced vigour (Blank et al, 1982).
Crumbly fruit varying from year to year in the same plantation were observed. The aim of the described trial within the COST action 836 was to find out, if special climatic conditions influence the amount of crumbliness. It was suggested that high temperatures increase crumbly fruit**.** There are two important periods concerning fruit development.

The first period is blossom time and fruit set. Negative conditions as too hot or cold weather or too much rain might lead to malformed fruit.

Temperatures above 25°C lead to a closing of the stomata. The plant supplies the organs with stored carbohydrates. High temperatures might injure any organs of the flower or supply channels for water, nutrients and hormones. Rain and cool weather influence the activity of the bees and might lead to an insufficient pollination.

The second period is the time of bud differentiation. Certain organs might develop incorrectly because of special climatic conditions. A normal development of the fruit is impossible in the following season.

The first observation year was 2003. This year may be characterized as too hot and too dry all over Europe during the vegetation period (at least from May until the end of August). At all trial sites the average temperature of 2003 was higher than in 2004 and 2005. Maximum temperature was in Villaviciosa (Spain) 25°C, in Beaucouzé (France) 30°C, in Etoile (France) 35°C, in Randwijk (The Netherlands) 34°C and in Weinsberg (Germany) 39°C.

A higher percentage of crumbly fruit may be expected in 2003 than in the following years. The data show (table 9) that in both years (2003 and 2004) the percentage of crumbly fruit was very low (below 5 %) Looking at the average of all data of all trial sites, it seems that the percentage was slightly higher in 2004 (average of `Meeker` Germany and France: 2,5 %) than in 2003 (average of `Meeker` Germany and France: 1 %). However because of the random occurrence and distribution of crumbly fruit a statistical analysis is not possible and therefore a statement cannot be made.

There is some variation in the rainfall among the trial sites. Most rainfall is measured in Villaviciosa (Spain) and lowest precipitation is recorded in Weinsberg (Germany) and Beaucouzé (France**).** No crumbly fruit were picked in the plantation of Beaucouzé and Villaviciosa (Spain). The amount of crumbly fruit in Weinsberg (Germany) and Randwijk (The Netherlands) was below 5 %. There is no influence of the precipitation visible on the amount of crumbly fruit.

The small differences between temperatures among the trial sites and the generally low amount of crumbly fruit do not indicate an influence of climatic conditions on the occurrence of crumbliness. The random distribution of crumbliness makes it more difficult to find a correlation between crumbliness and climatic conditions (temperature).

The average temperature increase of 1°C by a permanent plastic shelter did not show a correlation to crumbliness**.** In the same field a temperature increase of about 10°C on days with high solar radiation did not force crumbliness in comparison with the open field. Again a random distribution of this phenomenon was observed (Muster, 1999).

Muster (1999) found no correlation between cooling effects by overhead spraying of water and the occurrence of crumbliness, although the leaf temperature was decreased by 8°C to 10°C on summer days.

"Crumbly canes" were counted at the research station in Etoile, France, in the years 2003 and 2004 as well as in Weinsberg, Germany, in the year 2005.

The results mostly show either many crumbly canes in a plot or a few "crumbly canes". A high percentage of crumbly fruit correlates with a big number of "crumbly canes", as the results of the years 2003 until 2005 show in Weinsberg.

Jennings (1961) found crumbliness in clones of 'Malling Promise', 'Norfolk Giant' and 'Malling Jewel', and for each associated it with a somatic mutation. In 'Malling Jewel' and 'Latham' the disorder was associated with a mutation of the dominant allele at a heterozygous gene locus, causing plants to become homozygous for a recessive gene (Jennings, 1967). In 'Sumner' red raspberry variety crumbly fruit was found (Daubeny, 1967). In this case crumbly fruit is suggested to be caused by a mutation giving homozygosity for two recessive gene pairs, which retard embryo sac development and reduce the production of fertile pollen.

Thoss and Spiegler (1993) found two clones of 'Rumiloba'. One of the clones ('Rumiloba 1') had big and more conical shaped fruit. 'Rumiloba 2' produced crumbly fruit in a grower's plantation. They found that 'Rumiloba 2' was not sufficiently self-fertile and needs other varieties as '`Meeker`' or '`Schönemann`' as pollinator. Then the berries of 'Rumiloba 2' show a round form. They suggest that 'Rumiloba 2' is a mutation of 'Rumiloba 1'. It was also found that '`Meeker`' fruit had about 56 % of fertile pollen. They conclude that '`Meeker`' is sufficient self-fertile (Thoss et al., 1993). Investigations of the fertility of the varieties '`Meeker`' and '`Schönemann`' confirm self-fertility and a good germination rate of the pollen (Muster, 2002).

The conventional propagation by root cuttings of "crumbly canes" produced crumbly descendants (Licht, 2004). This character can also be propagated by tissue culture (Muster, 2005). It is suggested that crumbliness is caused by a mutation. This explains the continuity of crumbliness in the same plot in several years. Because of the thinning of the canes, it is not the exact same number each year**.** There might also be further stress factors for the plants, as heat for example, which leads to yearly differences. The random distribution of crumbliness in a plantation caused by a mutation covers the influences of other factors. Edin et al. (2000) compared `Meeker` plants either propagated by tissue culture or conventionally. They found that always some canes of one plant were "crumbly canes", but not all canes. Independent of the propagation method, there were "crumbly canes" in all variants. They suggest a genetic instability which stabilizes with increasing plant age. Crumbliness was not specially forced by means of tissue culture in this experiment.

Looking at the two `Meeker`-origins, there is a further difference which was not supposed to influence the trial. The `Meeker` plants originating from France were propagated in vitro whereas the `Meeker` plants from Germany were conventionally propagated. Crumbly fruit and crumbly canes are recognized in all variants. This confirms the results of Edin et al. (2000).

Feucht (et al., 1985) found a derivation of 0,65 % in the morphology of the plants after tissue culture. Crumbly fruit was recognized as well.

Tissue culture induces somaclonal variations (Mc Pheeters, 1988). The clonal stability is not always guaranteed (Skirvin, 1978). Swartz (1983) found no variability after either three subcultures in tissue propagation or conventional propagation. The results of the European trial suggest the appearance of crumbly fruit after both propagation methods. Because of the fact that genetic disorders are mainly associated with crumbly fruit and not with vegetative organs, there may be many cycles of vegetative multiplication before their presence is suspected (Jennings, 1988). The multiplication rate of conventional propagation is not as high as by tissue culture. Hence a defect in these plantations is more visible. As a precaution, fruiting plants should be part of any propagation programme to reduce crumbliness. Also the selection of motherplants may reduce crumbliness.

SUMMARY

Participants of the COST action 836 (Program of the European Union for cooperation in scientific and technical research) took part at a trial concerning crumbly fruit in red raspberry (Rubus idaeus L.). It was suggested, that the occurrence of crumbly fruit is influenced by climatic conditions. High temperatures should increase crumbliness. There were research stations involved in this trial from Great Britain**,** The Netherlands, Germany, France and Spain.

At all research stations plants with the same origin were used, as there were `Meeker` plants from Germany and France and `Tulameen` from Germany.

In the years 2003 until 2005 the amount of crumbly fruit was very low at all trial sites. Crumbliness was distributed randomly among the plots so that a statistical analysis was impossible. An influence of temperature cannot be proved. At the research station in Etoile (2003, 2004) and in Weinsberg (2005) canes, bearing only crumbly fruit (= crumbly canes) were counted. These canes were also randomly distributed in any variant. But the hypothesis of a somatic mutation as a cause for crumbliness can be confirmed because there are plots with always many “crumbly canes” or only few. The conclusion of tissue culture as a cause of crumbliness cannot be drawn. It seems that mutations may occur during any propagation process, but the extension of the damage is much higher after tissue culture because of more descendants. There is no test to detect the disorder apart from inducing these plants to fruit. Therefore nurseries should use fruiting mother plants for propagation purpose and select motherplants in advance.

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table 1: datas of soil of the trial sites

	Weinsberg	**Villaviciosa**	**Randwijk**	**Etoile**	**Beaucouze**
pH	6,2	7,3	7,5	7,1	7,2
Soil	loam	medium (franco)	river clay soil	clay + sand	clay+sand

table 2: datas of temperature and precipitation of the trial sites, 2003 - 2005

	2003				
	Weinsberg	Villaviciosa	Randwijk	Etoile	Beaucouze
temperature	10,7	14,2	10,5	14	12,9
precipitation	520	1056	682	876	809

	2004				
	Weinsberg	Villaviciosa	Randwijk	Etoile	Beaucouze
temperature	9,9	13,6	10,1	12,8	12,3
precipitation	542	1102	839	915	550

	2005				
	Weinsberg	Villaviciosa	Randwijk	Etoile	Beaucouze
temperature	11,1		10,5		13,6
precipitation	400		368		306

temperature: average temperature of the year (2005 only until September)
precipitation: sum of the year (2005 only until September)

Table 3: Percentage of crumbly fruit and crumbly canes at the station Weinsberg, Germany

		crumbly fruit		**crumbly canes**
			%	
	variant	2003	2004	2005
1-1-0-1	Meeker, K. Germany	0,5	0,8	1,4
1-1-0-2	Meeker, K. Germany	6,4	15,1	32,7
1-1-0-3	Meeker, K. Germany	0,7	1,6	3,4
average	Meeker, K. Germany	2,5	5,6	12,5
1-2-0-1	Meeker, France	0,2	1,8	7,9
1-2-0-2	Meeker, France	1,4	4,9	2,9
1-2-0-3	Meeker, France	6,8	1,2	6,9
average	Meeker, France	2,8	2,6	5,9
1-3-0-1	Meeker, Oberdorla	0,2	1,2	2,4
1-3-0-2	Meeker, Oberdorla	0,3	5,7	8,5
1-3-0-3	Meeker, Oberdorla	0,4	0,6	1,7
average	Meeker, Oberdorla	0,3	2,2	4,2
2-1-0-1	Tulameen, Germany	7,3	2,6	4
2-1-0-2	Tulameen, Germany	0,9	1,2	4,6
2-1-0-3	Tulameen, Germany	1,6	2,1	0
average	Tulameen, Germany	3,3	2,0	2,9
average	all Meeker variants	1,9	3,6	7,5
average	Meeker, Germany+France	2,7	4,2	9,2

Table 4: Percentage of crumbly fruit at the station in Villaviciosa, 2003 and 2004

		crumbly fruit in %	
Nr.	**Variante**	**2003**	**2004**
1-1-0-1	Meeker, K., Germany	0,2	0,0
1-1-0-2	Meeker, K., Germany	0,1	0,0
1-1-0-3	Meeker, K., Germany	0,0	0,0
average	Meeker, K., Germany	0,1	0,0
1-2-0-1	Meeker, France	0,0	0,0
1-2-0-2	Meeker, France	0,1	0,0
1-2-0-3	Meeker, France	0,0	0,0
average	Meeker, France	0,0	0,0
2-1-0-1	Tulameen, Germany	0,2	0,0
2-1-0-2	Tulameen, Germany	0,2	0,8
2-1-0-3	Tulameen, Germany	0,1	0,0
average	Tulameen, Germany	0,2	0,3

Table 5: Percentage of crumbly fruit at Manor Farm, Oxford, 2004-2005

Variante	**marketable fruit (g/plot)**		**crumbly fruit (%)**
	2004	**2005**	**2004/2005**
Tulameen, K., Germany	30.387	40.717	None recorded
Meeker, France	19.381	36.467	None recorded
Meeker, K., Germany	23.793	36.750	None recorded

Table 6: Percentage of crumbly fruit at the station in Beaucouze, 2003 - 2005

		crumbly fruit in %		
Nr.	**Variante**	**2003**	**2004**	**2005**
1-1-0-1	Meeker, K., Germany	0,0	0,0	0,0
1-1-0-2	Meeker, K., Germany	0,0	0,0	0,0
1-1-0-3	Meeker, K., Germany	0,0	0,0	0,0
average	Meeker, K., Germany	0,0	0,0	0,2
1-2-0-1	Meeker, France	0,0	0,0	0,0
1-2-0-2	Meeker, France	1,2	25,0	0,0
1-2-0-3	Meeker, France	1,6	12,5	1,2
average	Meeker, France	0,9	11,5	0,3
2-1-0-1	Tulameen, Germany	0,0	13,3	0,0
2-1-0-2	Tulameen, Germany	0,0		0,0
2-1-0-3	Tulameen, Germany	0,0	0,0	0,0
average	Tulameen, Germany	0,0	9,1	0,0

Table 7: Percentage of "crumbly canes" at the station in Etoile, France

		crumbly canes %	
	Variante	**2003**	**2004**
111	Meeker, K., Germany	0,1	26,0
1102	Meeker, K., Germany	17,0	29,0
1103	Meeker, K., Germany	0,1	50,0
average	Meeker, K., Germany	5,7	35,0
1201	Meeker, France	13,0	0,1
1202	Meeker, France	11,0	15,0
1203	Meeker, France	0,1	0,1
average	Meeker, France	8,0	5,1
2101	Tulameen, Germany	14,0	0,1
2102	Tulameen, Germany	13,0	12,0
2103	Tulameen, Germany	0,1	0,1
average	Tulameen, Germany	9,0	4,1
2201	Tulameen, France	29,0	38,0
2202	Tulameen, France	25,0	46,0
2203	Tulameen, France	0,1	0,1
average	Tulameen, France	18,0	28,0

Table 8: Percentage of crumbly fruit, 2003 at the station in Randwijk

	% crumbly fruit
	2003
Meeker, K. Germany	0,7
Meeker, France	0,7
Tulameen, Germany	1,3

table 9: Average percentage of crumbly fruit (canes) at the various trial sites

	2003	**crumbly fruit in %**				**canes %**	**average of crumbly fruit %**
	Randwijk	Beaucouze	Oxford	Villaviciosa	Weinsberg	Etoile	
Meeker	0,7	0,5	0	0,1	2,7	6,9	1
Tulameen	1,3	0	0	0,2	3,3	9	1,2

	2004	**crumbly fruit in %**				**canes %**	**average of crumbly fruit %**
	Randwijk	Beaucouze	Oxford	Villaviciosa	Weinsberg	Etoile	
Meeker	-	5,8	0	0	4,1	20	2,5
Tulameen	-	9,1	0	0,3	2	4,1	2,9

Meeker: origin: Germany and France
Tulameen: origin: Germany