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Experiences with the planting of *Sorghum bicolor* L (Moench) in Switzerland

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Abstract

Sorghum bicolor (L) Moench is one of the most important arable crops worldwide. Although the main cropping area lies in warm regions like India, Africa and America, sorghum is also cropped successfully in Europe. Surface planted with sorghum increased again during the past few years, among other reasons also because of the low pressure of insects and diseases and because its ability to outlast drought periods better compared to maize. Up to now little information about the cropping of sorghum in Switzerland was available. In order to gain information about the quantity and quality of sorghum grown in Switzerland, field trials with different varieties were established during the years 2009, 2010, and 2011. Best yields of the earliest maturing varieties in the year 2009 in the small plot experiment were satisfactory: up to 11.0 t ha^{-1} with a dry matter content of 84% at the time of the harvest. In order to meet the requirements for a fast development, a complete pollination and grain formation, only sites excluding natural depressions or wind-exposed sites and the prevention of too early seeding should be considered. The analyses of the grains showed, that the Swiss sorghum is of good quality and can compete for this aspect with imported sorghum. This successful cropping of sorghum in Switzerland shows, that more information on C4-species is necessary to Swiss farmers, as the availability of cultivars adapted to the climatic conditions in Switzerland can offer a solution to the changing conditions of the environment.

Keywords: sorghum, variety, field trials, amino acids, components

Introduction

Sorghum bicolor (L) Moench is one of the most important arable crops worldwide (FAOSTAT, 2012). Although the main cropping area lies in warm regions like India, Africa and America, sorghum is cropped successfully in Europe. France is the most important sorghum growing European country (FAOSTAT, 2012). Among other reasons surface planted with sorghum increase during the past few years also because of the low pressure of insects and diseases (Berenji and Dahlberg, 2004), because its ability to outlast drought periods better compared to maize and because early maturing varieties were selected by the breeders being well adapted at the respective growing conditions. Sorghum generally can be used not only as animal feed or for human consumption but also for industrial purposes such as the production of brooms, ethanol or biogas (Smith and Frederiksen, 2000; Dahlberg et al, 2011). Despite this multifunctional uses, up until now, it has hardly been planted in Switzerland.

Climate change and the expectation of dryer summer periods in some regions of Switzerland (Torriani et al, 2007) ask for the adaptation of existing crop rotations and the investigation of crops competing better with the expected environmental conditions. Sorghum has the characteristic to produce comparatively higher yields than maize with equal amounts of water, but more knowledge is needed to be able to grow this crop in regards to Swiss conditions. Although highly dependent on world market prices, sorghum is imported in considerable quantities to Switzerland, e.g. 12,600 t in 2008 for animal feed.

In order to gain information about the cropping of Sorghum in several regions of Switzerland, small plot experiments at two sites and on farm trials in six provinces using different early maturing varieties were conducted during three years. The quality of the harvested material was analyzed in two years.

Materials and Methods

Experimental sites

Field trials were conducted during the years 2009, 2010, and 2011. The fields for the small plot experiments were located in the Swiss midland in Zurich on a Cambisol in 2009 and on a gleyic Cambisol in the years 2010 and 2011 and in Hüntwangen on a Luvisol. Both sites belong to the favorable maize growing regions of Switzerland (Bundesamt für Landwirtschaft, 1977). The mean air temperature and the yearly precipitation of the past nine years was 9.8°C and 950 mm in Zurich and 10.0°C and 990 mm in Hüntwangen. During the growing period the sum of temperature (base 0°C) was 2,579°C, 2,620°C, and 2,626°C

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Table 1 - Description of the varieties of *Sorghum bicolor* (L) Moench grown at two sites in small plot experiments and in strip trials in Switzerland in the years 2009-2011 (breeders' information).

Name	Breeder	Country of the first registration (year)	Color of the grain	Sum of the temperature with base 6°C		Testing year in Switzerland
				Seeding until flowering	Seeding until 25% H_2O (grain)	
Ardito	Semences de Provence (F)	I (2005)	white			2009, 2010, 2011
Arfrio	Semences de Provence (F)	F (2003)	orange	800	1,785	2009, 2010, 2011
Friggo	R 2n (F)	F (2003)	orange - red	835	1,805	2009, 2010, 2011
Quebec	Semences de Provence (F)	F (1999)	orange – light brown	840	1,775	2009, 2010, 2011
Super Sile 15	Caussade Provence (F)	F (2010)				2009, 2010, 2011
Iggloo	R 2n (F)	I (2009)	orange	835	1,790	2010, 2011
Maya	Semences de Provence (F)	F (2008)	orange - red	840	1,805	2010
Arlys	Semences de Provence (F)	F (2003)	orange - red	850	1,815	2011

and the precipitation was 508 mm, 681 mm and 465 mm in the years 2009, 2010, and 2011, respectively in Zurich. At the site Hüntwangen during the growing period the sum of temperature was 2,717°C and 2,721°C and the precipitation was 528 mm and 555 mm in the years 2009 and 2011, respectively. In addition to the small plot experiments during the three years altogether ten strip experiments without replicates but with up to five different varieties, different row distances, seeding densities and seeding dates in various provinces in Switzerland were conducted.

Plant material and crop management

Early maturing hybrid varieties of *Sorghum bicolor* (L) Moench were selected (Table 1). All cultivars except Super Sile 15 which is recommended for the use of silage contained the dwarf-gen and thus can be harvested with a regular combine harvester. Due to the availability of seeds, varieties planted were not the same throughout the three years. Seeding was realized with a single grain seeder, appropriate for small plot experiments (Hege 95B), at a seeding depth of 3 cm and at a row spacing of 0.75 m. The variety trials were conducted at both sites with two different seeding densities (13.2 and 21.5 grains m^{-2}). Fertilization and weed control measures were based on French and Austrian guidelines and are summarized in Table 2. Total amount of nitrogen applied was split in up to three applications depending on the form of the fertilizer. In Hüntwangen additionally to the amount of synthetic fertilizer in the previous fall and early spring compost and farmyard manure was applied. When the experiments started, the types of herbicides recommended in the guidelines were not registered in Switzerland. The authorities allowed nonetheless the use of these herbicides as an exception not only for the purpose of the experiment but also to collect data for the future registering process of these products. Plots were harvested using a threshing machine (Wintersteiger plot combine, Nurserymaster Elite, Ried im Innkreis, Austria).

The strip trials, on the other hand, were managed by the farmers also according the Austrian and French recommendations and mainly harvested by the farmers with the available equipment. Representative samples of approximately 8 kg were taken from the harvested material to measure the dry matter content at the time of harvest and to investigate the components indicating the quality.

Measurements on the harvested grains

Water content at the time of harvest was determined with the NIT-technique on cleaned samples (Infratec Tecator 1241, FOSS Analytical, Hilleroed, Denmark). Harvested seeds were dried and yield (t ha^{-1}) adjusted to a dry matter content of 85.5%. Test

Table 2 - Management of *Sorghum bicolor* (L) Moench at the two sites (Zurich, Hüntwangen) in Switzerland in the years 2009 – 2011.

Agricultural practice		2009		2010	2011	
Description	Details	Zurich	Hüntwangen	Zurich	Zurich	Hüntwangen*
Previous crop		Winter wheat	Winter wheat	Temporary prairie	Temporary prairie	Sugar beet
Soil tillage	Ploughing	20 Nov 2008	Feb 2009	23 Nov 2009	29 Oct 2010	Feb 2011
	Seed bed preparation	20 May 2009	18 May	13 / 22 Apr 2010	9 May 2011	10 May
Seeding		23 May	19 May	23 Apr	10 May	11 May
Weed control	Dual Gold [l ha^{-1}] and	1.2 (2 Jun)	1.2 (Jun)	1.2 (29 May)	1.2 (30 May)	
	Stomp SC [l ha^{-1}]	2.2 (2 Jun)	2.2 (Jun)	2.2 (29 May)	2.2 (30 May)	
	Hoeing in between rows	10 / 22 Jun		29 May / 14 / 28 Jun	24 May / 16 Jun	
	Handweeding		Jul		15 / 18 Jul	Jun / Jul
Fertilisation	Phosphor [kg ha^{-1}]	70 (15 Apr)	92 (2 May)	92 (12 Apr)	70 (10 Mar)	197 (29 Apr)
	Nitrogen [kg ha^{-1}]	41 (22 May) 41 (10 Jun) 61 (22 Jun)	36 (2 May) 128 (12 May)	41 (30 Apr) 54 (29 May) 54 (14 Jun)	65 (24 May) 65 (16 Jun)	77 (29 Apr) 180 (30 May)
	Potassium [kg ha-1]		200 (2 May)	240 (12 Apr)	180 (10 Mar)	300 (29 Apr)
	Magnesium [kg ha-1]	3.75 (10 Jun)		3.75 (30 Apr) 5 (29 May) 5 (14 Jun)	6 (24 May) 6 (16 Jun)	
Harvest		28 Oct	27 Oct	28 Oct	18 Oct	17 Oct

*additionally also compost and solid farmyard manure was applied before ploughing.

Table 3 - Grain yield (t ha^{-1} with 85.5% DM), water content at the time of the harvest (humidity, %), test weight (kg hl^{-1}) and thousand kernel weight (TKW, g) of sorghum varieties grown at the two sites Zurich and Hüntwangen at a seeding density of 21.5 kernels m^{-2} (small plot experiments with three replications, 2009-2011).

Site and parameter	Year	Name of the variety								Mean	CV (%)	LSD (p = 0.05)
		Ardito	Arfrio	Friggo	Quebec	Super Sile 15	Iggloo	Maya	Arlys			
Zurich												
Grain yield (t ha^{-1})	2009	10.72	11.28	9.60	10.16	8.94				10.14	7.2	1.37
	2010	6.91	8.98	7.87	9.53	0.44	9.25	6.41		7.06	8.7	1.09
	2011	6.30	7.25	8.26	9.59	2.79	8.83		8.16	7.31	13.4	1.74
Humidity (%)	2009	16.8	17.8	19.6	16.2	24.9				19.1	30.3	ns
	2010	25.0	17.7	17.7	18.1	53.1	18.0	22.7		24.6	4.5	2.0
	2011	21.7	17.5	15.4	16.2	40.0	16.0		19.0	20.8	10.3	3.8
Test weight (kg hl^{-1})	2009	77.7	78.1	75.0	78.6	72.3				76.3	4.4	ns
	2010	76.4	78.2	74.8	79.4	nd	77.2	74.4		76.7	0.6	0.8
	2011	77.6	78.4	78.8	79.4	72.1	79.6		78.4	77.8	0.7	0.9
TKW (g)	2009	23.6	26.1	18.9	24.7	26.2				23.9	3.2	1.4
	2010	23.8	26.6	19.0	24.7	25.3	24.8	23.5		23.9	3.7	1.6
	2011	17.2	16.6	12.3	13.0	16.6	15.6		18.5	15.7	3.1	0.9
Hüntwangen												
Grain yield (t ha^{-1})	2009	10.69	10.68	9.67	9.83	10.53				10.28	4.8	ns
	2011	7.68	6.55	7.85	7.27	4.51	8.83		7.63	7.19	8.7	1.53
Humidity (%)	2009	15.4	19.4	18.8	18.3	17.0				17.8	23.3	ns
	2011	21.2	17.5	16.4	16.6	33.3	17.6		22.0	20.6	1.8	0.9
Test weight (kg hl^{-1})	2009	77.6	75.4	73.9	74.6	77.1				75.7	5.4	ns
	2011	77.4	79.1	79.9	77.4	71.2	78.0		77.4	77.2	1.0	1.3
TKW (g)	2009	23.6	27.4	17.8	22.6	28.2				23.9	4.5	2.0
	2011	16.2	13.9	12.3	10.7	16.0	12.7		15.7	13.9	3.5	0.9

CV = coefficient of variation; LSD = Least significant difference; ns = not significant at a probability level of p = 0.05

weight (kg hl^{-1}) was determined with a grain analysis computer (GAC® 2100, DICKEY-john, Auburn, USA) and the thousand kernel weight (TKW, g) was determined by weighing 250 grains. Bulked samples from the small plot experiments as well as samples from the strip trials were analyzed at the Institute for Livestock Sciences at Agroscope in Posieux for the following components: Nutrients were determined according the Weender analysis and the crude lipid (RL) after a chemical extraction with hydrochloric acid according the protocol from Berntrop (RLBT). For the analyses of the amino acids HPLC was used. Fatty acids were quantified according an adapted method at the Institute for Livestock Sciences at Agroscope in Posieux, based on the protocol form of Alves et al (2008, 2009). Afterwards values were converted for triglycerides (RLGC). This method allows for a better determination of the fatty acids when compared to RLBT and consequently results in higher values. The digestible energy content for pigs (DE) was calculated from nutrient content according ALP (2004).

Experimental design and statistical analysis

Experiments were established with a single factor consisting of the different varieties. A randomized complete block design with three replications was used. Plot size was 12 m^2 (3 m x 4 m) and consisted of four rows with a row distance of 0.75 m. The 6 m^2 plot size for yield evaluation was composed of the two centre rows. The two different seeding densities were established as independent experiments close to each other.

Due to significant interactions between the years, sites and varieties, evaluated parameters of the small plot experiment were investigated using a one-way ANOVA where the effects of the varieties are estimated on the basis of the fixed effects model (Snedecor and Cochran, 1987). An all pairwise multiple comparison procedures using the Fisher's LSD test ($P < 0.05$) was performed to determine varieties that differed significantly from each other. Due to heavy infestation of weeds in one replication at Hüntwangen in the year 2011, only two replications were taken into account for the evaluation of the grain yield and the water content at the time of the harvest. The statistical analyses were performed using WIDAS (MSI Dr. Wälti AG, Buchs, Switzerland).

Results and Discussion

Climatic conditions were similar at the two sites within the respective years but very different between the three years (data not shown). Due to the exposition in Zurich (natural depression in 2010 and 2011), the temperature after sowing or at the time of the flowering was different compared to the year 2009, where the trials were seeded later and established in a field exposed to south.

Observations in the field

The single grain seeding technique allowed a proper germination and a regular emergence. All the varieties developed side tillers – either in spring at the base or later, on the axils. Both tillering forms lead to an irregular maturation, because tardy flowering panicles have delayed maturity. No lodging of any variety was observed either during the vegetation period or

Table 4 - Mean grain yield (t ha^{-1} with 85.5% DM), water content at the time of the harvest (humidity, %), test weight (kg hl^{-1}) and thousand kernel weight (TKW, g) of sorghum varieties grown at two sites Zurich and Hüntwangen at a seeding density of 13.2 kernels m^{-2} (small plot experiments with three replications', 2009-2011).

Site and parameter	Year	Name of the variety								Mean	CV (%)	LSD (p = 0.05)
		Ardito	Arfrio	Friggo	Quebec	Super Sile 15	Iggloo	Maya	Arlys			
Zurich												
Grain yield (t ha^{-1})	2009	11.51	10.77	10.37	11.70	11.23				11.13	9.9	ns
	2010	7.05	9.02	7.53	8.47	0.52	8.52	5.80		6.70	5.9	0.71
	2011	5.64	5.06	8.32	9.95	4.26	7.62		7.02	6.84	13.2	1.60
Humidity (%)	2009	19.6	16.6	15.5	16.3	33.9				20.4	2.1	0.8
	2010	23.8	17.3	17.0	17.1	51.1	18.6	23.9		24.1	7.2	3.1
	2011	24.9	19.6	16.5	16.9	38.3	16.1		19.6	21.7	4.9	1.9
Test weight (kg hl^{-1})	2009	76.8	79.1	77.0	78.4	69.4				76.1	0.4	0.5
	2010	nd	nd	nd	nd	nd	nd	nd				
	2011	77.0	76.9	78.9	79.2	66.5	78.6		77.4	76.4	1.1	1.5
TKW (g)	2009	23.6	28.0	18.8	24.0	24.9				23.8	3.2	1.4
	2010	24.9	26.9	19.6	25.0	26.7	29.5	23.5		25.2	13.1	ns
	2011	16.8	16.0	12.5	12.7	15.1	15.2		17.8	15.2	1.6	0.4
Hüntwangen												
Grain yield (t ha^{-1})	2009	nd	nd	nd	nd	nd						
	2011	8.65	6.51	9.38	8.50	4.82	9.18		8.66	7.96	10.3	2.07
Humidity (%)	2009	nd	nd	nd	nd	nd						
	2011	20.9	20.6	17.5	15.7	33.6	17.4		18.9	20.6	7.9	4.0
Test weight (kg hl^{-1})	2009	nd	nd	nd	nd	nd						
	2011	78.0	77.4	79.7	77.6	71.1	78.0		78.1	77.1	0.8	1.1
TKW (g)	2009	nd	nd	nd	nd	nd						
	2011	16.3	15.4	12.6	10.8	16.7	13.5		16.4	14.5	3.1	0.8

CV = coefficient of variation; LSD = Least significant difference; ns = not significant at a probability level of p = 0.05; nd = not determined

at harvest time.

Hardly any pests and diseases were observed which corresponds with the statements of Berenji and Dahlberg (2004) based on the experiences in other European countries. On a small number of plants, feeding damage of *Ostrinia nubilalis* caused the panicle to break. But this phenomenon was rare. Almost every year sparrows (*Passeridae*) caused damage – mainly on the border rows. Concerning diseases, northern corn leaf blight (*Exserohilum turcicum*) was observed on a relatively low level.

Weed control was successfully carried out, except at the site Hüntwangen in 2011 where the optimal time for chemical weed control was missed, leading to a completely mechanical and manual weed control. Due to the heavy pressure of weeds, one replication was excluded from the evaluations, so as to maintain proper yield data for this site.

Yield and quality

Yield

Harvest took place at Zurich 158 (2009), 188 (2010) and 161 days (2011), respectively and at Hüntwangen 161 (2009) and 159 (2011) days after seeding. The comparatively high number of days to reach maturity in 2010 when compared to 2009 can be explained by the weather, the exposition and the seeding date of the trials (Table 2). Interesting yields ranging from 5 to 11.5 t ha^{-1} in Zurich and from 6.5 to 10.7 t ha^{-1} in Hüntwangen were attained (Tables 3 and 4). This is equal to or slightly higher than the level of the neighboring countries (FAOSTAT, 2012). The big variation between the three years ($P_{year} < 0.001$) as well as the significant interaction between the years and the varieties ($P_{year\ x\ variety} < 0.001$) can partly be explained by the fields chosen at Zurich for the experiments: in the years 2010 and 2011, the experiments were located in a natural depression, protected on one side by forest, causing mainly in cool times unfavorable growing conditions for the sorghum plants in the juvenile and flowering stage, which was not the case in 2009 or at the site in Hüntwangen. Varieties Super Sile 15 and Arfrio were more sensitive to this change of environment resulting in higher variability of the yield. This influence was less pronounced for the varieties Friggo and Quebec (Tables 3 and 4). The comparatively higher yield stability of Friggo when compared to Arfrio is also shown from the variety tests in France. To prevent the grains from absorbing the water coming from the green leaves and stems during the harvest process, cutting the stems at a height of approximately 0.7 m was a good choice. But from the economical point of view, this decision leads to additional cost for the mulching of the stubbles afterwards. Water content was comparatively low for all chosen varieties except for the variety Super Sile 15 indicating that, in the proper regions, sorghum can be harvested with a high dry matter (DM) content in time to seed a winter wheat crop afterwards.

Arfrio is, among the tested varieties in France, described as one of the highest yielding varieties with a very early maturing genotype. In the experiments conducted here, Arfrio has not always given the highest yields. But because in France and Austria the recommended seeding densities are higher than

Table 5 - Mean content (g kg-1 DM +/- standard deviation) of ash (CA), crude protein (CP = N*6.25), crude fat (RL), fat triglyceride (RLGC), crude fibre (CF), nitrogen free extract (NFE), acid detergent fibre (ADFB), neutral detergent fibre (NDFB), saturated fatty acids (SAT), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), PUFA-MUFA-Indice (PMI= MUFA*1.3+PUFA), digestible energy for swine (DE) and the ratio of the PMI with DE (PMI_rel) of eight varieties of *Sorghum bicolor* (L) Moench grown at different sites in Switzerland (2010-2011).

Name of the variety	Number of samples analyzed n	CA g kg-1 DM	CP g kg-1 DM	RL g kg-1 DM	RLGC g kg-1 DM	CF g kg-1 DM	NFE g kg-1 DM	ADFB* g kg-1 DM
Ardito	6	18.6 +/- 1.22	121.1 +/- 17.98	40.5 +/- 2.81	51.9 +/- 3.46	15.6 +/- 3.97	804.2 +/- 18.74	66.4 +/- 5.18
Arfrio	6	18.4 +/- 2.18	131.9 +/- 21.70	38.2 +/- 2.35	47.3 +/- 3.45	14.4 +/- 2.76	797.1 +/- 21.61	66.6 +/- 3.64
Arlys	3	19.1 +/- 0.77	136.7 +/- 2.54	40.7 +/- 0.39	52.1 +/- 1.09	11.2 +/- 0.79	792.3 +/- 3.40	
Friggo	8	16.0 +/- 1.58	109.3 +/- 11.45	35.1 +/- 2.07	47.6 +/- 2.52	17.5 +/- 4.07	822.2 +/- 11.84	62.6 +/- 8.69
Iggloo	8	17.8 +/- 1.17	118.5 +/- 13.11	38.4 +/- 2.05	49.6 +/- 1.23	20.7 +/- 3.84	804.6 +/- 16.30	50.4 +/- 0.43
Maya	3	17.9 +/- 0.93	119.8 +/- 16.07	33.6 +/- 0.55	46.7 +/- 0.72	16.4 +/- 4.69	812.4 +/- 15.22	
Quebec	4	17.7 +/- 1.48	113.5 +/- 9.28	40.6 +/- 1.38	50.5 +/- 2.16	14.2 +/- 2.30	814.0 +/- 7.48	55.8 +/- 10.44
Super Sile 15	2	21.4 +/- 0.50	142.3 +/- 5.40	39.2 +/- 0.85	45.9 +/- 1.67	20.0 +/- 1.06	777.0 +/- 5.69	67.7 +/- 3.04
Mean	40	17.9 +/- 1.90	121.2 +/- 17.41	38.1 +/- 3.07	49.1 +/- 3.15	16.6 +/- 4.45	806.2 +/- 18.98	62.3 +/- 8.67

Name of the variety	Number of samples analyzed n	NDFB* g kg-1 DM	SAT g kg-1 DM	MUFA g kg-1 DM	PUFA g kg-1 DM	PMI g kg-1 DM	DE MJ kg-1 DM	PMI_rel g MJ DE-1
Ardito	6	154.6 +/- 31.15	7.5 +/- 0.30	15.3 +/- 1.35	26.7 +/- 1.93	46.5 +/- 3.64	16.7 +/- 0.02	2.8 +/- 0.21
Arfrio	6	205.5 +/- 8.58	7.0 +/- 0.20	12.9 +/- 1.63	25.2 +/- 1.75	42.0 +/- 3.79	16.8 +/- 0.03	2.5 +/- 0.23
Arlys	3		7.3 +/- 0.16	15.8 +/- 0.30	26.7 +/- 0.81	47.2 +/- 1.12	16.8 +/- 0.01	2.8 +/- 0.07
Friggo	8	165.6 +/- 61.40	6.3 +/- 0.30	14.0 +/- 1.05	24.9 +/- 1.28	43.2 +/- 2.59	16.7 +/- 0.04	2.6 +/- 0.15
Iggloo	8	117.7 +/- 6.51	7.0 +/- 0.21	15.3 +/- 0.42	25.1 +/- 1.14	45.0 +/- 1.03	16.7 +/- 0.02	2.7 +/- 0.06
Maya	3		6.8 +/- 0.25	14.1 +/- 0.21	23.7 +/- 0.47	42.1 +/- 0.72	16.7 +/- 0.02	2.5 +/- 0.04
Quebec	4	131.3 +/- 38.50	7.5 +/- 0.29	14.7 +/- 1.01	26.1 +/- 0.90	45.2 +/- 2.10	16.8 +/- 0.03	2.7 +/- 0.12
Super Sile 15	2	156.6 +/- 4.31	6.6 +/- 0.11	11.7 +/- 0.60	25.3 +/- 1.13	40.5 +/- 1.91	16.7 +/- 0.01	2.4 +/- 0.11
Mean	40	157.4 +/- 46.73	7.0 +/- 0.49	14.4 +/- 1.49	25.4 +/- 1.59	44.1 +/- 3.18	16.7 +/- 0.03	2.6 +/- 0.19

*Samples for the analyses of ADFB and NDFB were two for the varieties Arfrio, Iggloo, Quebec, Super Sile 15, four for Ardito and six for Friggo

21.3 grains m^{-2} (which may explain this difference), the interaction of seeding density and variety as well as seeding density and row space needs to be investigated more precisely.

Every year, in Hüntwangen, maize (*Zea mays* L) was planted in the ultimate proximity of the sorghum trials. In the years 2009 and 2011, sorghum yields reached respectively 65 and 60% of the actual and early maturing maize varieties. Due to the considerable amounts of precipitation, it is assumed that, sorghum being better adapted to drier conditions compared to maize, could not compete with maize with its yield in the tested conditions.

Quality

The test weight varied between 77 and 80 kg hl^{-1} with significant influence of the variety but the ranking at the sites in the different years was not always the same (Tables 3 and 4). As for the test weight, the thousand kernel weight differed between the varieties. Though, for the year 2011, a considerable reduction was observed for all varieties (Tables 3 and 4). This may be due to the lower precipitation during the grain filling period (data not shown).

Also for the nutritional components, a diversity between the varieties was detected (Tables 5 and 6). In general for the nutrients, Swiss sorghum contained a slightly higher content of protein (CP), ADF and NDF when compared to the French database (INRA, 2012). Otherwise the content of the nutrients as well as the content of the energy are comparable. Since for the analyses of the nutritional components also samples from the strip trials with only one or two varieties were included, differences between varieties observed may be due to the different origin of the samples. Information presented in Tables 5 and 6 thus reflects more a monitoring of the Swiss sorghum production in the years 2010 and 2011. Since the contents of lipids and energy are comparable to that of maize (*Zea mays* L) in Switzerland, the use of sorghum as swine feed has to be done carefully in order to prevent a discount due to bad quality of the lipid at the time of the slaughtering.

Results of the analyses of the amino acids for 3 varieties (n=14) are presented in Table 6 and are in line with other investigations (Smith and Frederiksen, 2000; INRA, 2012). The composition of the amino acids is similar to the one of maize with the exception of tryptophan for which maize has a lower content.

Conclusions

It is possible to grow *Sorghum bicolor* (L) Moench in Switzerland. Due to economic reasons (e.g. drying costs) or agronomic experiences (e.g. yield stability, seeding date of the following crop), only Friggo and Quebec can be recommended for Switzerland, among the varieties tested during three years. But in favorable growing conditions, some of the higher yielding varieties may develop an interesting yield level.

In order to gain more information about the influence of row distance and the best seeding density as well as the behavior of some varieties with a higher yield potential in the best sorghum growing regions in Switzerland, specific trials are needed. Since the advantage of sorghum to compete better with water

Table 6 - Comparison of the composition of amino acids (means +/- standard deviation) in the grains of selected varieties of *Sorghum bicolor* (L) Moench grown in Switzerland (2009-2011) with the values in the INRA database (Association Française de zootechnie, io-7 Version 4.6.3, 2012, www.feedbase.com).

Name of the variety		Ardito	Friggo	Iggloo	Mean	Mean database INRA
Number of samples analyzed	n	4	8	2	14	
Crude protein	(g kg^{-1} DM)	132 +/- 9.16	111.0 +/- 8.44	98.6 +/- 2.56	115.4 +/- 14.16	107.8 +/- 11.20
Alanine	(g kg^{-1} DM)	11.9 +/- 1.02	10.7 +/- 0.72	9.5 +/- 0.30	10.6 +/- 1.17	10.8 +/- 1.90
Arginine *	(g kg^{-1} DM)	4.4 +/- 0.36	3.9 +/- 0.23	3.6 +/- 0.09	4.0 +/- 0.40	4.7 +/- 0.60
Aspartic acid	(g kg^{-1} DM)	8.9 +/- 0.61	7.5 +/- 0.45	7.1 +/- 0.17	7.9 +/- 0.84	8.3 +/- 1.30
Cystine *	(g kg^{-1} DM)	2.0 +/- 0.18	1.9 +/- 0.11	1.7 +/- 0.10	1.9 +/- 0.17	2.3 +/- 0.30
Glutamic acid	(g kg^{-1} DM)	27.0 +/- 2.50	22.8 +/- 1.71	20.7 +/- 0.72	23.7 +/- 2.90	25.0 +/- 4.10
Glycine	(g kg^{-1} DM)	3.7 +/- 0.27	3.4 +/- 0.18	3.2 +/- 0.16	3.4 +/- 0.28	3.7 +/- 0.40
Histidine *	(g kg^{-1} DM)	2.7 +/- 0.22	2.4 +/- 0.19	2.2 +/- 0.11	2.5 +/- 0.25	2.7 +/- 0.30
Isoleucine *	(g kg^{-1} DM)	5.3 +/- 0.45	4.6 +/- 0.32	4.2 +/- 0.12	4.8 +/- 0.50	4.8 +/- 0.80
Leucine *	(g kg^{-1} DM)	17.5 +/- 1.67	14.9 +/- 1.10	13.3 +/- 0.47	15.4 +/- 1.87	16.1 +/- 2.70
Lysine *	(g kg^{-1} DM)	2.7 +/- 0.14	2.3 +/- 0.09	2.3 +/- 0.07	2.4 +/- 0.20	2.5 +/- 0.30
Methionine *	(g kg^{-1} DM)	2.2 +/- 0.13	1.8 +/- 0.15	1.6 +/- 0.09	1.9 +/- 0.24	2.0 +/- 0.30
Phenyl-alanine *	(g kg^{-1} DM)	6.9 +/- 0.62	5.9 +/- 0.41	5.3 +/- 0.18	6.1 +/- 0.71	6.3 +/- 1.00
Proline	(g kg^{-1} DM)	10.8 +/- 1.11	9.4 +/- 0.65	8.5 +/- 0.25	9.6 +/- 1.09	10.1 +/- 1.60
Serine	(g kg^{-1} DM)	5.7 +/- 0.52	5.0 +/- 0.37	4.7 +/- 0.22	5.1 +/- 0.55	5.5 +/- 0.80
Threonine *	(g kg^{-1} DM)	4.2 +/- 0.30	3.6 +/- 0.21	3.4 +/- 0.15	3.8 +/- 0.37	3.9 +/- 0.50
Trypto-phan *	(g kg^{-1} DM)	1.4 +/- 0.08	1.2 +/- 0.08	1.1 +/- 0.03	1.3 +/- 0.13	1.2 +/- 0.20
Tyrosine *	(g kg^{-1} DM)	5.3 +/- 0.53	4.4 +/- 0.34	4.0 +/- 0.15	4.6 +/- 0.59	4.7 +/- 0.80
Valine *	(g kg^{-1} DM)	6.5 +/- 0.50	5.6 +/- 0.36	5.2 +/- 0.15	5.8 +/- 0.60	5.9 +/- 1.00

*indispensable amino acids

stress and heat compared to maize becomes only true in dryer environmental conditions, for yield-maximizing farms, sorghum is an option only in areas such as Geneva, the north-west, the north-east or the southern part of Switzerland. If other characteristics such as the resistance to *Diabrotica virgifera* or Fusarium species or the composition of the grain become important, this crop could also be interesting to be planted in other regions.

Analyses of the components indicate that the quality of Swiss sorghum is of good quality for animal feeding. Nevertheless these interesting facts, surface planted in Switzerland at the moment depends on the sorghum and maize price on the world market.

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