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Organic Lentil Production in Switzerland: Evaluation of Genotypes for Agronomical, Qualitative, and Sensory Traits

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Abstract

Lentils constitute a strategically important crop within sustainable agricultural systems, particularly in the context of rising global demand for plant-based protein sources. In Switzerland, approximately 95% of lentil seeds are imported, underscoring the untapped potential for domestic production. This study systematically evaluated the performance of multiple lentil genotypes, alongside optimal seeding densities and growing seasons, through a series of field experiments conducted over five years. In addition, a sensory evaluation was performed on 12 selected genotypes to assess consumer-relevant quality traits. The findings revealed substantial variability in yield among genotypes, ranging from 0.9 to 1.6 t/ha; however, interannual variation exerted a more pronounced influence, with yields fluctuating between 0.1 and 2.0 t/ha. Notably, autumn-sown lentils achieved yields of up to 2.7 t/ha in three out of four growing seasons, even among genotypes lacking full winter-hardiness, indicating significant production potential under appropriate management conditions. Optimal plant densities were identified within the range of 180–240 plants/m^2. From an economic standpoint, higher seeding densities appear justifiable, as the increased seed costs are offset by corresponding gains in yield. Since intercropping of lentils with oats did not negatively affect grain yield nor the thousand kernel weight, the benefits of this cropping system are highlighted. Sensory analysis demonstrated statistically significant differences in attributes such as mealiness and juiciness, leading to the classification of genotypes into three distinct sensory clusters. Despite these differences, overall sensory variation was relatively limited, suggesting that genotype selection may be guided primarily by agronomic performance, climatic adaptability, and winter-hardiness, as well as by market preferences for seed colour and size. Collectively, these results highlight the potential of autumn sowing as a viable strategy to enhance lentil production and reduce the risk of crop failure in Swiss agricultural systems.

Keywords: *Lens culinaris*; seeding date; seeding density; quality; agronomy; sensory

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Academic Editor: Alfonso Albacete

Received: 6 March 2026
Revised: 25 April 2026
Accepted: 13 May 2026
Published: 21 May 2026

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1. Introduction

Lentils (*Lens culinaris* Medikus) are one of the oldest grain legume crops domesticated in ancient times [1]. Their seeds are used for human diet, and their straw can be used for animal feed. Their main cropping areas are India and Canada, but they are also cultivated in several European countries, such as Spain, Greece, and France, or in Turkey on more than 100,000 ha [2]. The average grain yield in Europe is 0.96 t/ha, which varies depending

on the region, year, and cultivation method [2]. To meet Switzerland's increasing consumer demand for plant-based proteins [3], the import of lentils increased by 167% between 2004 and 2023, reaching 3390 t in 2023 [4]. Since the area cultivated with lentils currently consists of only about 200 ha [5], there are possibilities to increase the growth area due to lack of native lentils but additionally due to changing environmental conditions becoming more favourable for lentil growing [6].

Due to the comparatively low need for fertilisers and their ability to fix nitrogen, lentils are particularly suitable for extensive cropping systems and marginal soils. Compared with other arable crops, lentils are better at tolerating droughts and high temperatures. Since summer droughts are expected to become more frequent [6,7], the interest of farmers in growing lentils in Switzerland has increased. This is particularly true for certified organic farms because selling price is more competitive compared to imported lentils. However, due to the plant's poor early vigour, competition with weeds is a major challenge [8], especially in organic farming systems [9]. Moreover, poor resistance to lodging often leads to additional efforts to eliminate stones and soil particles from lentil seeds prior to selling. To address both obstacles, it is recommended, and in Central Europe often applied, that lentils be grown in mixtures [10,11]. Several studies demonstrate benefits of intercrops with legumes [12], but little information about lentil–oat mixtures exist [10,11]. To investigate whether yield stability could be increased with mixed cropping, lentils were established with oat (*Avena sativa* L.) when sown in spring or with camelina (*Camelina sativa* (L.) CRANTZ) when sown in autumn.

Although it is known that increasing plant density can be an effective means for suppressing weeds in arable crops [13–15], information about optimal density for lentils seems region-specific [16–18] and no information was found on this topic from central European countries.

Besides the importance of the appropriate cropping system, the choice of the most suited variety remains essential. A huge diversity of germplasm for lentils exists [19]. Up to now, neither information about performance of different lentil varieties nor the advantages and inconveniences of summer versus fall sown varieties are documented for Switzerland. Although several advantages of fall-sown pulses are known [20–22] little information about cropping of winter-hardy lentils in general is documented [8,22]. Given the increased interest in their cultivation, breeders started developing such genotypes more than a decade ago [22,23].

Last but not least, to develop a sustainable lentil production, this should be in line with consumers' wishes. As a consequence, besides high value of components of lentils [24,25], it is important to know whether varieties differ in sensory aspects and meet consumers' taste.

Thus, the aim of this study was to evaluate various factors for successful lentil cropping in Switzerland by conducting field experiments with different (i) genotypes either as sole cropped or intercropped, (ii) seeding densities established in (iii) two growing seasons. Additionally, the analysis of protein seed content and sensory traits of different lentil genotypes was applied and also the economic benefit for farmers following organic culture with different seeding densities was evaluated.

2. Materials and Methods

2.1. Field Experiments

2.1.1. Site-Specific Information

The experiments were established during the years 2015–2019 in the proximity of Zurich (47°25′13″ N 8°31′51″ E; 459 m a.s.l.) in organically managed fields. Long-term precipitation and average temperature (1981–2023) between March and August were 575 mm and 13.9 °C [26]. The soils were gleyic Cambisols.

2.1.2. Genotypes and Treatments

From 2015 to 2017, we established experiments with 10 lentil genotypes in autumn and also in spring (Table 1). These genotypes were chosen due to their different agronomical characteristics, earliness, seed sizes, and colours, representing germplasm used in some other neighbouring European countries. To increase the genetic variability, three commercial lentil varieties from Greece, one genotype from the genebank (IPK, Gatersleben, Germany) were added as well as two varieties commercialised by the Swiss cooperative Biofarm. The experiments established in spring were duplicated: once as a sole crop and once in a mixture together with oat (*Avena sativa* L., varieties Kurt [2015–2016] and Troll [2017]), at a density of 180 viable lentils m^{-2} and 60 viable oats m^{-2}, respectively. In addition to the sole crop established in autumn 2017, a mixture with camelina (*Camelina sativa* L.) was investigated and sown in autumn at a rate of 9.8 kg/ha. In 2018, the performance of two winter-hardy lentil genotypes (Toni and Morton) was compared with a Beluga genotype and three genotypes from the first investigation period (Anicia, Späth's Kleine, and Kleine Schwarze). Different seeding densities (120, 180, 240, 320, and 360 seeds m^{-2}) were investigated over two years (2018 and 2019) for the genotype Kleine Schwarze established both in autumn and in spring.

2.2. Crop Management and Traits Measured

The experiments were established at the end of October/beginning of November (autumn-sown, AS) and at the end of March/beginning of April (spring-sown, SS) with a small plot seeder TC or a Hege 76 (Wintersteiger AG, Ried, Austria) with seven rows, an interrow distance of 0.18 m, and a density of 240 viable seeds m^{-2}, which was calculated according to prior conducted germination tests. Neither fertiliser nor pesticides were applied, and weeds were mostly controlled twice by hoeing and harrowing (Table 2).

During the growing season, soil cover after winter (%), the beginning of anthesis (date), and resistance to lodging at maturity were recorded in the experiments established in autumn 2018 and 2019. For the seeding density experiments, the effective plant density was evaluated on a sub-plot. The dry matter content of the grains at the time of harvest was evaluated by weighing a subsample twice: before and after drying at 105 °C for 24 h. The yield was evaluated on dried samples after harvesting with an experimental combine (Wintersteiger AG, Ried, Austria), followed by winnowing and separation, if crops were mixed. Residual moisture after drying was determined using a grain analyser (Infratec™ 1241, Foss GmbH, Hamburg, Germany). The thousand kernel weight (TKW) was evaluated using a Marvin analyser (GTA Sensorik GmbH, Neubrandenburg, Germany). Protein content was measured with NIRFlex N-500 (BÜCHI Labortechnik AG, Flawil, Switzerland) after establishing a calibration based on chemical analyses of part of the samples. The calibration was done based on nitrogen evaluations from the laboratory, and the values were multiplied by the factor 6.25, which is common for lentils and used by breeders [27]. Protein yield was calculated by multiplying yield and protein content.

The seed costs were calculated by multiplying the seed rate (Formula (1)) with the seed price (Formula (2)).

$$seed\ rate\left(\frac{kg}{ha}\right) = \frac{TKW\ (g) \times number\ of\ seeds\ per\ m\hat{}2}{germination\ rate\ (\%)} \quad (1)$$

$$seed\ costs\left(\frac{CHF}{ha}\right) = seed\ price\left(\frac{CHF}{kg}\right) \times seed\ rate\left(\frac{kg}{ha}\right) \quad (2)$$

The calculation was done with a seed price of CHF 5.20 per kg, a TKW of 19.6 g, and a germination rate of 95%. The mean economic benefit per ha was calculated using a price of

CHF 5.08 per kg of seeds (price for organic lentils), 8% moisture, and the corresponding grain yield.

Table 1. Lentil genotypes (name, breeder, and provider) established in two growing seasons (autumn and spring) in the proximity of Zurich (CH) under conditions of organic farming (2015–2019).

Name	Appearance [1]	Seed Colour	Breeder (Country)	Provider	Years Investigated [2]				
					2015	2016	2017	2018	2019
Anicia		Olive green marbled	INRA (France)	OH Samen, Rafz, CH	X	X	X	X	X
Späth's Kleine		Light green–beige	Fritz Spaeth (Germany)	Albleisa, Lauterach, DE	X	X	X	X	X
Kleine Schwarze		Black	Not known	Genebank, IPK Gatersleben, DE	X	X	X	X	X
Rosana		Red-brown	INRA (France)	OH Samen, Rafz, CH	X	X	X		
Santa		Ocre	INRA (France)	OH Samen, Rafz, CH	X	X	X		
Flora		Ocre	INRA (France)	OH Samen, Rafz, CH	X	X	X		
Samos		Greenish yellow	Industrial & Fodder Crops Inst. of the Hellenic Agricultural Organization (Greece)	Breeder	X	X	X		
Thessalia		greenish yellow	Industrial & Fodder Crops Inst. of the Hellenic Agricultural Organization (Greece)	Breeder	X	X	X		
Dimitra		Greenish yellow	Industrial & Fodder Crops Inst. of the Hellenic Agricultural Organization (Greece)	Breeder	X	X	X		
Berglinse		Light brown	Not known	Biofarm Genossenschaft, Kleindietwil, CH	X	X	X		
Beluga		Black	Not known	Biofarm Genossenschaft, Kleindietwil, CH				X	X
Toni		Light brown	Montana State University (USA)	Breeder				X	X
Morton		Light brown	Montana State University (USA)	Breeder				X	X

[1] © Taken by Vinoth Ratnam (Agroscope), included with consent. [2] The letter X indicates the year in which each variety was grown.

Table 2. Crop management and site-specific information for experiments with different lentil genotypes (2015–2019) and seeding densities (2018–2019) established in two growing seasons per year (in autumn, AS, and in spring, SS) in the same field in the proximity of Zurich (CH).

Year	2015		2016		2017		2018		2019	
Growing Season	**AS**	**SS**	**AS**	**SS**	**AS**	**SS**	**AS**	**SS**	**AS**	**SS**
Previous Crop	Potato		Winter wheat		Potato		Temporary grassland		Silage maize	
Sowing (Date)	31 Oct 14	9 Apr 15	20 Oct 15	29 Mar 16	1 Nov 16	28 Mar 17	26 Oct 17	19 Apr 18	24 Oct 18	26 Mar 19
Mechanical Weed Control (Date)	By hand (May 8)	Hoeing & harrowing (May 13 & May 29)	Harrowing (Mar 13); hoeing (Mar 23 & Apr 21)	Harrowing (Apr 21 & May 26)	Harrowing (Mar 16 & Apr 24); hoeing (Mar 28 & Apr 24)	Hoeing & harrowing (Apr 24); hoeing (May 24)	Hoeing (Apr 24 & May 7)	Hoeing (May 7)	Hoeing & harrowing (Mar 27)	Hoeing & harrowing (May 17); hoeing (Jun 5)
Harvest (Date)	Jul 15	Jul 28	Jul 20	Aug 2	Jul 13	Jul 19	Jul 10	Jul 31	Jul 22	Aug 1
Growing Period (d)	257	110	274	126	254	113	258	104	271	129
Sum of Temperature (°C) [1]	2257	1892	2432	1922	2173	1772	2215	1885	2383	1935
Lowest Temperature (°C)	−15.6 (Dec 29)		−10.5 (Jan 18)		−15.1 (Jan 7)		−13.1 (Feb 28)		−7.3 (Jan 3)	
Precipitation (mm) [1]	726.2	389.7	893.5	577.8	578.4	308.3	626.9	203.5	741.8	354.2

[1] During growing period; base 0 °C.

2.3. Sensory Analysis

A panel of 10 assessors (6 female, 4 males; 27–60 years) performed an exploratory generic descriptive analysis [28]. All assessors were experienced in the sensory evaluation of plant products but had no prior lentil-specific profiling experience. The panel was therefore used as a small trained expert panel for exploratory descriptive profiling rather than for formal panel performance validation. Two 45-min training sessions were conducted on 18 and 25 September 2018. In the first session, assessors generated descriptors individually and the final descriptor list was defined by consensus under the guidance of the panel leader. The second session was used to align scale use and descriptor interpretation across a wide range of lentil genotypes. The formal evaluation took place once on 9 October 2018, i.e., each genotype was evaluated once by each assessor.

To obtain comparable firmness across genotypes, the samples were cooked in water for genotype-specific durations (Supplementary Material, Table S1). Cooking times were determined in a preliminary test by sensory consensus of the panel leader and a trained sensory assistant. The samples were served in 21.5 cL ISO wine-tasting glasses labelled with three-digit codes and assessed with spoons. Descriptors were rated on unstructured 0–100-line scales using RedJade® 2.13.32 sensory software (Curion, Redwood City, CA, USA), with 0 indicating "not present", "low" (overall aroma, juicy), or "homogeneous" (homogeneity shell/interior), and 100 indicating "high" or "inhomogeneous". Presentation order was balanced according to a Williams Latin square design, and water was provided as a palate cleanser between samples. Tastings were conducted in a sensory laboratory with 12 laterally separated seats, white lighting, appropriate ventilation, and room temperature conditions.

Because the sensory study was conducted as a single evaluation session without repeated measurements, the data allow exploratory product profiling and product discrimination, but they do not permit a formal estimation of within-assessor repeatability or panel reproducibility.

2.4. Experimental Design and Statistical Analyses

The experiments were established in a completely randomised block design with three replicates for each treatment. All treatments were randomly assigned within each block. The plot size was 1.5 m × 6.0 m. Statistical analyses were performed using R (RStudio Server Pro 1.2.5033-1, Boston, MA, USA). An analysis of variance (ANOVA) using the aov() function on the effect of genotype, sowing time, crop management (sole crop versus mixture), and seeding density was performed. The full factorial model included all main effects and their interactions. The significance of main and interaction effects was evaluated using F-tests. When significant effects were detected, pairwise comparison was done with Tukey's honestly significant difference (HSD) test with a 0.05 probability level. Mean comparisons are shown with different letters indicating statistically significant differences. Pearson's product–moment correlation was used for the analysis of the seeding density trials. All figures were established using Excel and the GGPLOT 2 version 4.0.3 package of R.

For the sensory data, genotype effects were analysed descriptor-wise using ANOVA for a randomised complete block design, with genotype as the fixed effect and assessor as the blocking factor. Given the balanced design, this approach is equivalent to the standard mixed model testing of product effects with genotype treated as fixed and assessor as a random source of variation in descriptive sensory studies. When the global genotype effect was significant ($p < 0.05$), Tukey-adjusted pairwise comparisons were performed using estimated marginal means.

Model assumptions were checked on model residuals through visual inspection of residual versus fitted and normal Q–Q plots and were supplemented by Shapiro–Wilk tests for residual normality and Brown–Forsythe tests for homogeneity of variance across genotypes. Several descriptors deviated from residual normality, whereas Brown–Forsythe tests did not indicate relevant heterogeneity of variances across genotypes. Because the design was balanced and the Friedman sensitivity analysis identified the same significant descriptors as the parametric approach, the ANOVA results were retained and interpreted cautiously. In addition, Pearson correlation coefficients were calculated on genotype mean descriptor intensities averaged across assessors to explore associations among descriptors.

To explore similarities among genotypes, a hierarchical cluster analysis was performed on the non-standardised genotype mean profiles using Euclidean distances and Ward's method. The three-cluster solution was treated as exploratory and was visualised by cutting the dendrogram at the corresponding height.

3. Results

The year had a remarkable influence on the success of lentil growth. Two years had very promising yields (2017 and 2018), whereas some years showed very low or almost no yields (2016). There was overall too much precipitation in the early period of 2016, followed by a dry period, whereas precipitation was comparatively low in some years, particularly 2018. Thus, overall ANOVA resulted in significant interactions, with the consequence of presenting most data on a single experimental level and the difficulty of generalising conclusions.

3.1. Cropping System

3.1.1. Grain Yield

In all three years (2015–2017), oats mixed with lentils did not negatively affect the grain yield of lentils, although the seeding density of the lentils was reduced by 25% compared with the sole crop (Table 3). The differences among lentil genotypes used in this study, have been observed and yields ranged from 0.3 (Berglinse) to 1.9 t/ha (Rosana) in 2015 and

from 1.0 (Santa) to 2.1 t/ha (Kleine Schwarze) in 2017. Extreme conditions in 2016 led to extremely low yields in both the sole and mixed crop lentils.

Table 3. Grain yield (t/ha), protein yield (t/ha), protein content (%), and TKW (g) of 10 lentil genotypes tested as sole crop (sole) or as a mixture (intercropping) with oat as estimated from data selected at two spring growing seasons (2015 and 2017) in the proximity of Zurich (Switzerland) on an organically certified field.

	Grain Yield [t/ha] [1,2]				Protein Yield [t/ha] [1,2]				Protein Content [%] [2]				TKW [g] [2]			
	2015		2017		2015		2017		2015		2017		2015		2017	
Genotype	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**	**Sole**	**Mix**
Anicia	1.5 ^{a}	1.3 ^{ab}	1.8	1.6 ^{ab}	0.4 ^{a}	0.4 ^{ab}	0.5 ^{ab}	0.5 ^{ab}	29.5 ^{ab}	28.9 ^{ab}	28.2 ^{ab}	28.1 ^{ab}	30.5 ^{ab}	31.0 ^{bc}	32.2 ^{ab}	33.2 ^{bcd}
Berglinse	0.3 ^{b}	0.3 ^{c}	2.2	1.9 ^{bc}	NA [3]	0.1 ^{c}	0.6 ^{ab}	0.5 ^{bc}	NA	29.1 ^{ac}	28.2 ^{ab}	28.5 ^{abc}	29.6 ^{bd}	37.0 ^{ef}	38.5 ^{e}	38.5 ^{e}
Dimitra	1.1 ^{ab}	0.7 ^{ac}	1.7	1.3 ^{ac}	0.3 ^{a}	0.2 ^{bc}	0.5 ^{ab}	0.4 ^{ac}	29.9 ^{ab}	29.1 ^{ac}	28.1 ^{ab}	28.7 ^{ad}	35.8 ^{e}	39.6 ^{f}	43.5 ^{f}	42.7 ^{f}
Flora	1.5 ^{a}	1.7 ^{bd}	1.6	1.8 ^{ab}	0.4 ^{a}	0.5 ^{ad}	0.5 ^{ab}	0.5 ^{bc}	30.1 ^{ab}	29.8 ^{bc}	29.5 ^{cd}	29.5 ^{cd}	27.5 ^{ad}	29.3 ^{acd}	29.0 ^{ag}	29.8 ^{acg}
Kleine Schwarze	1.4 ^{a}	1.7 ^{bd}	2.3	2.1 ^{b}	0.4 ^{a}	0.5 ^{ade}	0.7 ^{a}	0.6 ^{b}	30.9 ^{b}	29.9 ^{bc}	30.2 ^{c}	30.1 ^{d}	20.8 ^{g}	21.4 ^{g}	23.7 ^{h}	24.9 ^{hi}
Rosana	1.5 ^{a}	1.9 ^{b}	1.7	2.0 ^{bc}	0.5 ^{a}	0.6 ^{a}	0.5 ^{ab}	0.6 ^{bc}	30.5 ^{bc}	30.3 ^{c}	29.4 ^{cd}	29.9 ^{d}	26.9 ^{d}	26.8 ^{d}	27.1 ^{gh}	27.6 ^{gi}
Samos	1.0 ^{ab}	1.0 ^{ad}	1.8	1.6 ^{ab}	0.3 ^{a}	0.3 ^{bce}	0.5 ^{ab}	0.4 ^{ab}	28.9 ^{a}	28.3 ^{a}	27.4 ^{a}	27.5 ^{a}	46.4 ^{h}	48.3 ^{h}	51.1 ^{j}	47.7 ^{j}
Santa	1.3 ^{a}	1.2 ^{ab}	1.6	1.0 ^{a}	0.4 ^{a}	0.4 ^{bd}	0.5 ^{ab}	0.3 ^{a}	29.2 ^{ac}	29.0 ^{ab}	28.9 ^{bd}	29.1 ^{bd}	29.5 ^{bd}	32.6 ^{b}	35.6 ^{be}	36.2 ^{de}
Späth's Kleine	1.1 ^{a}	1.2 ^{ab}	1.7	1.8 ^{ab}	0.3 ^{a}	0.4 ^{ab}	0.5 ^{ab}	0.5 ^{bc}	30.5 ^{bc}	30.2 ^{cd}	29.7 ^{cd}	29.8 ^{d}	22.3 ^{g}	23.3 ^{g}	24.3 ^{hi}	25.3 ^{hi}
Thessalia	0.8 ^{ab}	0.6 ^{ac}	1.6	1.5 ^{ab}	0.2 ^{a}	0.2 ^{bc}	0.4 ^{b}	0.4 ^{ab}	29.7 ^{ab}	29.0 ^{abd}	28.1 ^{ab}	28.4 ^{abc}	51.6 ^{i}	56.7 ^{j}	61.4 ^{k}	60.6 ^{k}
total mean	1.1	1.2	1.8	1.7	0.4	0.3	0.5	0.5	29.9	29.3	28.8	29.0	32.1	34.6	36.6	36.6
SD	0.5	0.6	0.3	0.4	0.1	0.2	0.1	0.1	0.8	0.7	0.9	0.9	9.6	10.8	11.9	10.9
CV (%)	39.6	48.3	18.8	23.5	29.1	49.5	20.1	24.9	2.6	2.4	3.2	3.2	30.0	31.1	32.5	29.8
df factor	9	9	9	9	8	9	9	9	8	9	9	9	9	9	9	9
df residual	20	20	20	20	18	20	20	20	18	20	20	20	20	20	20	20
F	6.1	12.2	2.3	4.4	3.0	13.2	2.6	5.2	4.7	7.3	15.2	10.4	285.3	351.9	431.9	265.2
P	0.000	0.000	0.054	0.003	0.026	0.000	0.035	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2	0.734	0.846	0.513	0.666	0.570	0.855	0.541	0.702	0.676	0.768	0.873	0.824	0.992	0.994	0.995	0.992

[1] Standardised to 8% moisture. [2] Different letters in the same column indicate significant differences ($\alpha = 0.05$, mixed model ANOVA, Tukey's HSD post hoc test). [3] NA = not measurable.

AS lentils cultivated in mixed cropping with camelina in 2017 exhibited yields that were approximately one-third (0.74 t/ha) of the sole cropped lentils (2.21 t/ha). Hence, we assume that camelina strongly competed with the lentils while efficiently suppressing the weeds. We therefore suggest reducing the seeding density of camelina to reduce its competition with lentils and developing a mixed cropping system with camelina for autumn sowing.

3.1.2. Quality Traits

Although in 2015 TKW slightly was higher in mixed cropping compared to the sole cropped lentils, no differences in TKW were observed for any of the genotypes sown in combination with oats or as sole crops in spring (Table 3). However, there was the exception of the two genotypes in 2015, Berglinse and Dimitra, which had nearly 25% higher TKW when cropped together with oat compared with sole cropping. In autumn 2017, when lentils were additionally established in mixed cropping with camelina, the average TKW (34.5 g) was significantly lower than in the respective sole cropping (35.5 g), but the TKW of the genotypes Anicia and Rosana was 2% and that of Berglinse was up to 4% higher when grown with camelina instead of as when grown as sole crops. The genotype-specific differences between the varieties remained mainly unchanged and Thessalia had the highest and Kleine Schwarze the lowest TKW.

Protein content was slightly higher in 2015 (29.3%) compared to 2017 (29.0%) when averaged over all genotypes but no clear effect of the cropping system was observed (Table 4). The differences between genotypes have been detected and remained similar

between the cropping systems. Although the differences were small, the highest values were observed for genotypes Flora, Kleine Schwarze, Rosana, and Späth's Kleine and the lowest for Samos.

Table 4. Lodging (rate: 1 = no lodging, 9 = completely lodged) of six lentil genotypes prior to harvest sown in autumn (AS) and spring (SS) in the proximity of Zurich (Switzerland) on an organically certified field (2018, 2019).

	2018		2019	
Genotype	**AS** [1]	**SS** [1]	**AS** [1]	**SS** [1]
Anicia	2.7 ± 0.94 [b]	6.2 ± 0.24 [ab]	7.0 ± 1.41 [a]	8.0 ± 0.00 [a]
Beluga	6.3 ± 0.47 [a]	5.3 ± 0.47 [ab]	7.7 ± 0.94 [a]	8.0 ± 0.00 [a]
Kleine Schwarze	6.3 ± 0.94 [a]	6.3 ± 0.47 [a]	7.3 ± 0.47 [a]	7.3 ± 0.94 [a]
Morton	7.7 ± 0.47 [a]	4.3 ± 0.47 [b]	7.7 ± 0.47 [a]	8.0 ± 0.00 [a]
Späth's Kleine	3.3 ± 0.47 [b]	6.0 ± 0.82 [ab]	7.7 ± 1.25 [a]	8.0 ± 0.00 [a]
Toni	7.0 ± 0.82 [a]	5.0 ± 0.82 [ab]	8.3 ± 0.47 [a]	7.0 ± 0.82 [a]
Total mean	5.6	5.5	7.6	7.7
SD	2.1	0.9	1.0	0.7
CV (%)	37.2	17.1	13.6	8.7
df factor	5	5	5	5
df residual	12	12	12	12
F	16.23	3.53	0.46	1.51
P	0.000	0.034	0.800	0.260
R^2	0.870	0.600	0.160	0.390

[1] Different letters in the same column indicate significant differences (α = 0.05, mixed model ANOVA, Tukey's HSD post hoc test).

With respect to both years (2015 and 2017; in 2016, no protein measurements were possible due to the low yield), the genotypes Kleine Schwarze and Rosana had high protein yields when sown together with oats in spring, but they were significantly different only from Dimitra, Berglinse, and Thessalia in 2015 and only from Santa in 2017. For the genotypes Flora, Rosana, and Späth's Kleine, the protein yields were higher in both years with mixed cropping than when grown as sole crops.

Similarly to the grain yield, in 2017, the protein yield for the AS lentils sown with camelina (0.22 t/ha on average) was very low compared with sole AS lentils, which showed a protein yield of 0.62 t/ha, on average. When sown together with camelina, Kleine Schwarze had a significantly higher protein yield (0.35 t/ha) than Thessalia (0.09 t/ha) but did not differ significantly from the other eight genotypes.

3.2. Growing Season

3.2.1. Agronomic Characteristics

Within the first three experimental years (2015–2017), the time from seeding to flowering was the longest in the 2016 season and was 71 days on average for the investigated genotypes when SS and 205 days when AS. This was approximately 13 days more compared with the 2015 season and 5–10 days compared with 2017 (2015: 58 days SS, 191 days AS; 2017: 66 days SS, 195 days AS). On average, AS lentils flowered 23 days earlier (mid-May) than SS lentils (beginning of June). The time range between the earliest and latest flowering genotypes was 13 days longer in AS compared to SS (5 days). Generally, Thessalia flowered the earliest, while Rosana and Anicia flowered the latest in both SS and AS. Averaged over the years 2015–2017, Santa flowered earlier than Anicia in SS, while Greek genotypes Thessalia and Dimitra flowered earlier than Rosana in AS. Based on the data from the second trial period (2018–2019) it is obvious that lodging depended not only on the genotype but also on the year and the growing season (Table 4). Less lodging was observed in 2018

compared with 2019. Anicia and Späth's Kleine showed the least lodging in 2018 with AS (Table 4).

3.2.2. Grain and Protein Yield

On average, AS lentils exhibited higher yields in 2015–2017 than SS lentils (Figure 1a, Table 3). This was particularly evident for the genotypes Kleine Schwarze, Samos, Santa, Späth's Kleine, and Thessalia. In contrast to that, Berglinse and Rosana seemed to perform better when SS. Protein yield in general was low but due to small differences in protein content it was generally higher for AS lentils (Figure 1b).

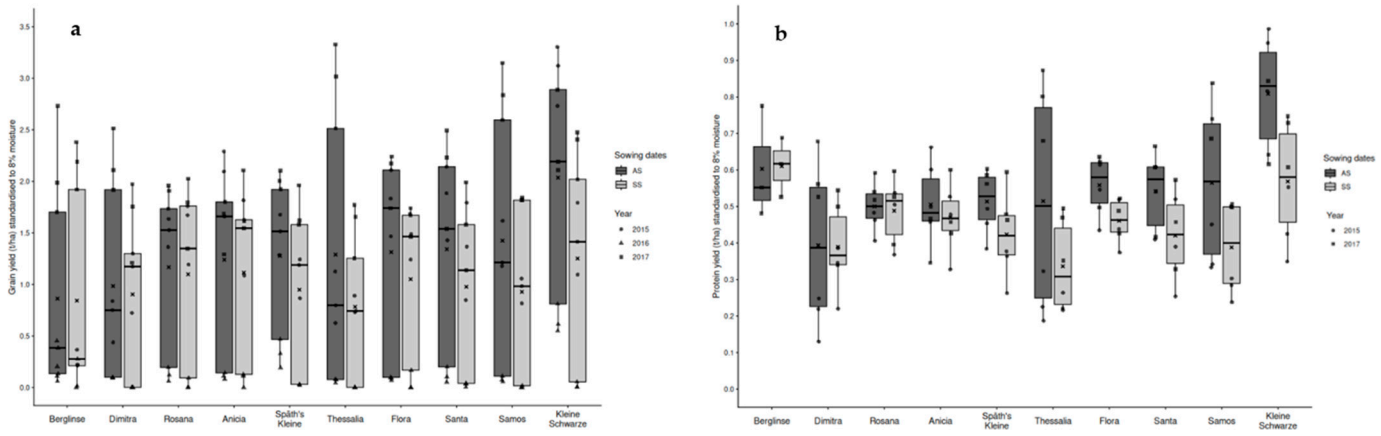

Figure 1. Grain yield ((**a**), t/ha) and protein yield ((**b**), t/ha) standardised to 8% moisture of 10 different lentil genotypes investigated from 2015 until 2017. Lentils were established as a sole crop and always sown in autumn (AS) and spring (SS) in the same area in the proximity of Zurich (Switzerland) on an organically certified field. Box plots represent the median, 25th, and 75th percentiles. "x" represents the mean.

In the second testing period (2018–2019), the average grain yield was higher for SS genotypes than for AS genotypes, except for Morton and Toni (Figure 2a). As a consequence, protein yields of winter-hardy lentils Toni and Morton were higher after AS compared with SS (Figure 2b); for the other four genotypes, it was the opposite.

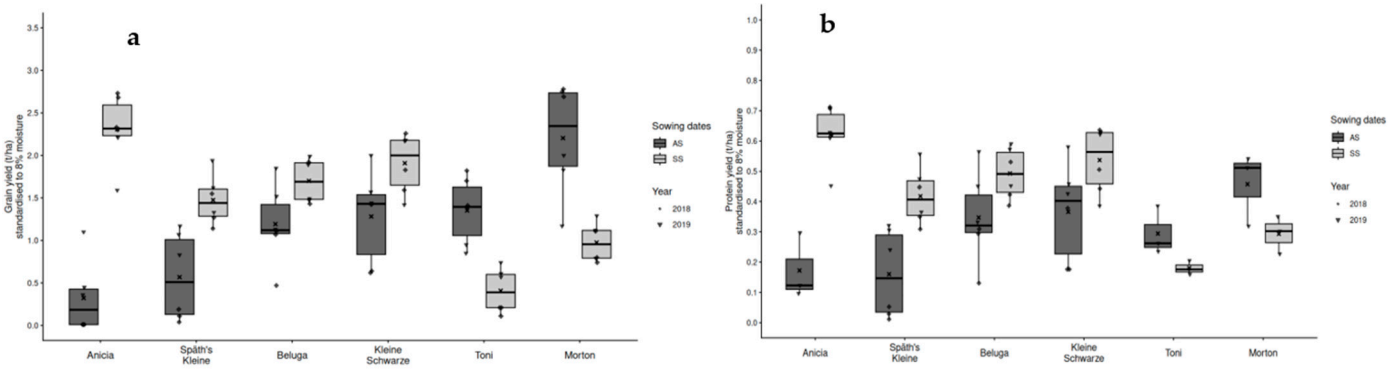

Figure 2. Grain yield ((**a**), t/ha) and protein yield ((**b**), t/ha) standardised to 8% moisture of six different genotypes investigated in 2018 and 2019. Lentils were established as a sole crop and always sown in autumn (AS) and spring (SS) on the same area in the proximity of Zurich (Switzerland) on an organic certified field. Box plots represent the median, 25th, and 75th percentiles. "x" represents the mean.

3.2.3. Quality Traits

In both testing periods, the year and genotype highly influenced the TKW, while the growing season did not. In the first testing period (2015–2017), the highest average

TKW over all genotypes occurred in 2017 (36.1 g), and the lowest occurred in 2016 (25.8 g). Considering the average TKW of individual genotypes over the complete first testing period, Thessalia and Samos had the highest TKW (51.2 g and 41.4 g, respectively), while Kleine Schwarze (19.9 g) and Späth's Kleine (23.3 g) had the lowest TKW. The genotype with the smallest TKW variation throughout the first testing period was Späth's Kleine. In the second testing period (2018–2019), the average TKW of Anicia and Morton was the highest, while the TKW of Beluga and Kleine Schwarze was the lowest.

The protein content of the different genotypes was influenced by the year, with the dry year 2017 exhibiting lower average protein content (28.3%) than the wetter year 2016 (29.7%). In 2015 and 2017, protein content of Kleine Schwarze, Späth's Kleine, and Rosana was significantly higher than that of Samos, Santa, and Anicia. In the second testing period (2018–2019), no significant differences were observed in protein content of the genotypes across the two growing seasons, AS and SS. However, similarly to the first testing period, significant effects of both the year (2019: 28.4%; 2018: 27.4%) and the genotype (Beluga, 28.9%; Anicia, 26.9%) were observed in both years.

3.3. Seeding Density

Although the seeding density of Kleine Schwarze was calculated considering the effective germination rate (%), only 90% of the intended density was achieved (Figure 3). In general, field emergence was independent of the seeding density—95% in SS and 80% in AS experiments. In all experiments, lodging neither increased nor decreased with increasing plant density. Regarding grain yield, significant effects were observed either by the year (1.68 t/ha in 2018 and 1.91 t/ha in 2019) or the growing season (1.69 t/ha after AS and 1.9 t/ha after SS). With increasing plant density, grain yields also increased ($r = 0.54$, $p < 0.001$).

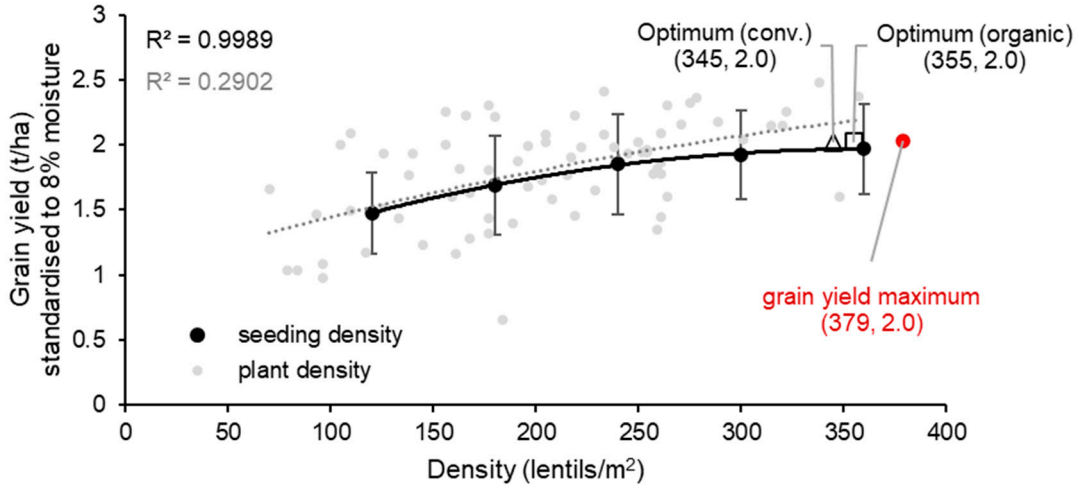

Figure 3. Grain yield (t/ha) standardised to 8% moisture of lentil as function of plant density observed in the trials (lentils/m^2, grey points) compared with the seeding density (black points). Error bars correspond to standard errors of the seeding density. Dotted grey line: effective function. Maximum grain yield and economically optimal seeding density for producer prices of 3.00 CHF/kg lentils (conventional farming) and 5.08 CHF/kg lentils (organic farming).

Furthermore, dry matter content of the seeds at harvest was significantly correlated ($r = 0.34$, $p = 0.004$) with plant density across all years and growing seasons. TKW of the genotype Kleine Schwarze was significantly higher in 2018 (20.7 g) compared to 2019 (18.6 g), and SS Kleine Schwarze had a significantly higher TKW (21.2 g) than respective AS seeds of the same genotype (18.1 g). Protein content was influenced by the year. In 2019, lentils showed, on average, higher protein content (29.7%) than those from 2018 (28.0%).

Overall, plant density of the investigated genotype Kleine Schwarze neither influenced its TKW (r = 0.11, $p > 0.3$) nor its protein content (r = 0.06, $p > 0.6$). Protein yield varied between 0.19 t/ha (240 seeds per m^2; AS 2018) and 0.73 t/ha (360 seeds per m^2; SS 2019) and increased with increasing plant density (r = 0.53, $p < 0.001$). Additionally, protein yield was, on average, higher in 2019 (0.57 t/ha) than in 2018 (0.47 t/ha), and SS lentils showed higher yields (0.55 t/ha) compared to AS lentils (0.49 t/ha).

Economic Benefits

Economic benefits of the investigated lentils were significantly higher in 2019 than in 2018 when SS and AS values were combined for each year. Additionally, across both years, SS lentils were significantly more profitable than AS lentils. Nevertheless, the differences in economic benefits for seeding densities of 180, 240, 300, and 360 seeds per m^2 did not differ (Table 5).

Table 5. Mean economic benefits (per ha) for the lentil genotype Kleine Schwarze sown at five different densities (120, 180, 240, 300, and 360 seeds per m^2) using a cost of CHF 5.20/1 kg seeds, calculating with a thousand kernel weight of 19.6 g and a germination rate of 95% and assuming a selling price of CHF 5.08/1 kg (price for organic lentils).

Seeding Density [Lentils/m^2]	Seed Quantity [kg/ha]	Costs of Organic Seeds [CHF/ha]	Achieved Grain Yield [t/ha] [1,2]	Economic Benefits of Organic Farming [CHF/ha] [2]
120	24.8	128.7	1.476 [a]	9476.5 [a]
180	37.1	193.1	1.690 [ab]	10,446.5 [ab]
240	49.5	257.5	1.851 [b]	11,161.0 [ab]
300	61.9	321.9	1.926 [b]	11,456.8 [ab]
360	74.3	386.2	1.971 [b]	11,609.8 [b]
Total mean			1.800	10,885.3
SD			0.400	1895.1
CV (%)			22.2	17.4
df factor			4	4
df residual			67	67
F			3.617	2.949
P			0.010	0.026
R^2			0.178	0.150

[1] Standardised to 8% moisture. [2] Different letters in the same column indicate significant differences ($\alpha = 0.05$, mixed model ANOVA, Tukey's HSD post hoc test).

Based on the available data, the quadratic production function is best suited to explain the yield effect of different seeding densities (Figure 3). A maximum yield of 2.03 t/ha was achieved at a plant density of 380 lentils/m^2. Higher seed densities lead to lower economic yields. At a producer price of 5.08 CHF/kg lentils for organic farming systems, the economically optimal seeding density of 355 lentils/m^2 was just below the maximum, and at a producer price of 3.00 CHF/kg lentils for conventional farming systems, it was 345 lentils/m^2.

Apart from the costs of sowing, the producer price for the seeds sold has an impact on the optimal seeding density (Figure 4). Seed prices are currently low, and producer prices are relatively high in Switzerland, which means that the influence of both factors on seeding density is low. Nevertheless, a rise in the seed price to 6 CHF/kg with a concurrent fall in the producer price to 2 CHF/kg lentils could have an impact on the economically optimal seeding density, reducing it to 304 lentils/m^2.

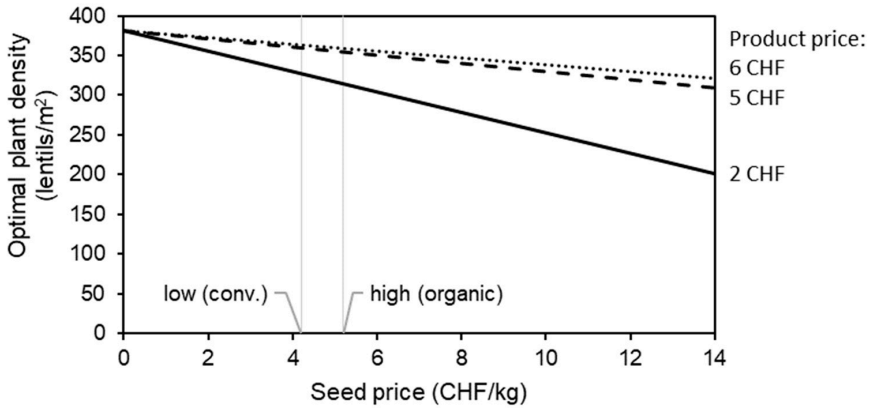

Figure 4. Economically optimal seeding density (lentils/m^2) depending on the price of the seeds (CHF/kg) and the producer price of 2, 5, and 6 CHF/kg lentils.

3.4. Sensory Analysis

The descriptor-wise analysis revealed significant genotype effects for two mouthfeel descriptors, mealiness ($F_{11,99} = 2.92$, $p = 0.002$), and juiciness ($F_{11,99} = 2.82$, $p = 0.003$), whereas no significant genotype effects were detected for overall aroma, herbal/hay, nutty/cereal, spices, fruity/floral, sweet, salty, bitter, or shell/interior homogeneity (all $p \geq 0.13$; Supplementary Table S3). Genotype mean intensity ratings (mean ± SE) are reported in Supplementary Table S2. Tukey-adjusted comparisons indicated higher juiciness ratings for Santa than for Samos, Berglinse, and Rosana, whereas no pairwise comparison remained significant for mealiness after adjustment (Supplementary Table S4). Several descriptors deviated from residual normality, but Brown–Forsythe tests did not indicate relevant heteroscedasticity; a Friedman sensitivity analysis with assessor as block supported the same two significant descriptors (Supplementary Table S3).

Hierarchical clustering of genotype mean profiles suggested three exploratory similarity patterns (Figure 5). Flora and Toni formed a cluster characterised by comparatively low sweetness and mealiness together with higher saltiness and bitterness. Berglinse, Kleine Schwarze, and Rosana formed another cluster with comparatively low saltiness and low-to-moderate mealiness. The remaining genotypes grouped together and showed comparatively higher sweetness and mealiness. Pearson correlations among genotype mean descriptor intensities are shown in Supplementary Figure S1 and Supplementary Table S5.

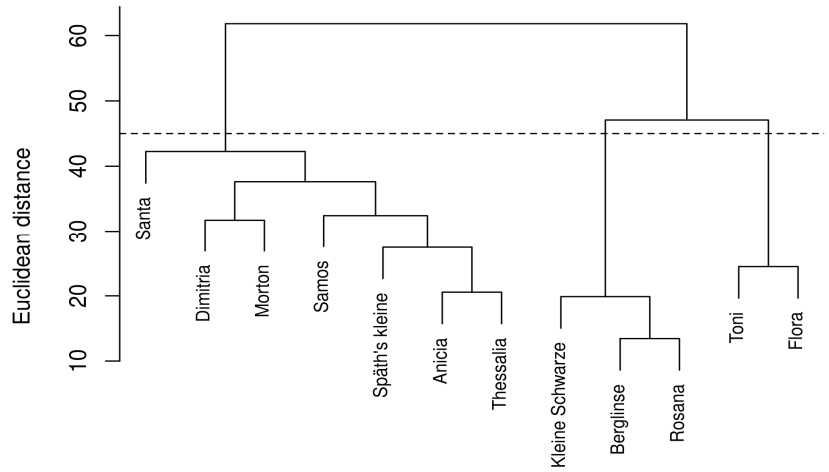

Figure 5. Exploratory sensory similarities among the 12 lentil genotypes. Dendrogram of hierarchical clustering based on non-standardised genotype mean intensities across sensory descriptors, using Euclidean distances and Ward's method. The dashed horizontal line indicates the exploratory cut-off used to display the three-cluster solution.

4. Discussion

The year had a remarkable influence on the success of lentil growth. Two years had very promising yields (2017 and 2018), whereas particularly in 2016 yield was very low. Thus, overall ANOVA resulted in significant genotype x year interactions, with the consequence of presenting most data on a single experimental level. Since lentils are better adapted to regions with little precipitation [2], from the results in 2016 it is concluded that there was overall too much precipitation in the early period, leading plants to starve while in the other years and particularly in 2018 precipitation was low and more favourable for lentil growth.

4.1. Cropping System

In the presented experiments no negative effects on the investigated lentil genotypes from oat have been observed [10,11]. Grain yield of lentils in mixed cropping with dwarf-straw oat varieties was generally even higher under the more difficult growing conditions in 2015 while in 2017 the performance of the sole cropped lentils tended to be higher. Absence of effects on the protein yield, but positive effects on the TKW at challenging growing conditions highlight the benefits of lentils intercropped with oats. Strong influence of camelina on lentil yield after AS showed the importance of appropriate seeding density or growth habit of partners within mixed cropping systems and sensitivity of lentils to competition [9]. In the presented trial, density was likely not well chosen or the plants grew too tall and shaded the lentils. More trials are necessary with either camelina or other winter-hardy species to develop mixed lentil cropping systems also for AS. In the presented study, even in mixed cropping, mechanical weed control was applied to prevent weeds to dominate. If weeds are intended to be controlled entirely by companion plants or lentils, further studies would be necessary to quantify the potential of changing seeding densities as well proportion of seeds within the intercropping systems [8,18].

Since Thessalia and Dimitra, the genotypes with the highest TKW, did not show increased performance in mixed cropping, which is in contrast to genotypes Rosana, Flora, Späth's Kleine, and in particular Berglinse in 2015 support the statements, that particular genotypes are needed for intercropping to exploit the potential [29]. Under temperate conditions, companion plants may reduce lodging, preventing pods from being close to the soil and enabling better seed quality (TKW).

Focusing on the quantity of proteins produced per land unit—a major need for future cropping systems—mixed cropping is more promising for lentils, particularly since in the present study the quantity additionally produced with oat has been omitted.

4.2. Growing Season

Independent of genotype-specific differences, AS led to earlier flowering and in most years to higher yields, which was particularly evident for the genotypes Kleine Schwarze, Samos, Santa, Späth's Kleine, and Thessalia (Figure 1a; [22]). Though, only in the years 2018 and 2019, harsh conditions caused severe damage to some of the genotypes investigated, greatly reducing the yield for AS genotypes compared to SS genotypes, except for Morton and Toni (Figure 2a). With respect to the sowing date, these grain yield differences can be explained by the fact that during these years, there were cold winters with little or no snow cover or freezing temperatures in spring after plants had already started to increase growth, resulting in the death of lentils with little winter-hardiness (Anicia, Beluga, Kleine Schwarze, Späth's Kleine), whereas spring-sowing of these genotypes bore no risk. However, Morton and Toni are winter-hardy genotypes. In fact, these genotypes showed better soil cover after winter when compared to others and were confirmed by measuring grain yield. Nevertheless, the need for vernalisation of these two genotypes was obvious if

sown in spring. The higher yields of AS lentils compared to SS lentils in 2015–2017 could be due to the absence of frost-killing temperatures (winters with low temperatures and the lack of snow protection), which is in line with earlier findings that earlier sowing dates potentially increase yields [8,18,22,30]. Nevertheless, to exploit the grain yield potential of lentils, earlier sowing or even autumn-sowing should be evaluated in relation to the potential of noxious weeds to germinate at a given sowing date. Especially for lentils sown in autumn, the risk of crop failure can be reduced by using winter-hardy types. Nevertheless, organising seeds can be a challenge, since no European seed multiplication of winter-hardy genotypes is known, and particular attention should be given to weeds germinating in autumn. This could be a challenge in organic farming systems and when facing unfavourable conditions in autumn or early spring. The earlier start of flowering of lentils after autumn-sowing could be advantageous, as this can protect flowering from hot/dry periods, thus also helping in stabilising yield [21,22].

From an economic point of lentil production, well-formed grains are essential to assure quality. In both testing periods, the year and genotype highly influenced the TKW, while the sowing date did not. The genotype with the least TKW variation throughout the first testing period was Späth's Kleine. Therefore, this genotype can be considered the least sensitive to stress in relation to TKW. In dry years, such as 2017, all genotypes had very high grain weight, which was—with the exception of Anicia (AS), Kleine Schwarze (AS), and Späth's Kleine (AS)—drastically reduced in 2016, a year that presented challenging growing conditions. During that year, the grain weight was 5–36% lower than the average over all three years. In the second testing period (2018–2019), the average TKW of Anicia and Morton was the highest, while the TKW of Beluga and Kleine Schwarze was the lowest. Considering the grain yield of these years, these findings suggest that lentils are better adapted to regions with little precipitation, especially during the grain filling/seed setting period.

In general, protein yield strongly correlated with the grain yield. In 2016, the overall protein yield was very low due to the low grain yields (Figure 1). Despite the fact that 2016 was a challenging year for lentils, genotypes Kleine Schwarze, Späth's Kleine, and Berglinse are worth mentioning, as their establishing in autumn did not completely fail and yielded 0.65, 0.33, and 0.22 t/ha, respectively. Therefore, importance of screening various genotypes, even from genebanks, seems a promising and important strategy, along with the development of new cultivars [19,25] to develop future lentil cropping systems.

4.3. Seeding Density

No negative effects on lodging have been observed with increasing seeding density. In line with other studies, significant effects have been detected [15–18]. Though, in contrast to drier regions, the optimal seeding density is much higher than 100–200 seeds/m^2 [15–17] and calculated to 340–350 seeds/m^2, which is similar to the range reported for Lithuania [18]. Due to the fact that field emergence was not as intended and that it was mostly below 360 plants/m^2 for the highest densities, additional trials are necessary to prove the findings. Since dry matter content of seeds at harvest was significantly correlated ($r = 0.34$, $p = 0.004$) with plant density across all years and sowing times, it seems important for temperate regions to state that higher seeding densities may modify the development of non-productive branches and pods, thus helping to fix the harvest date while using resources more efficiently [18]. Since some studies clearly recommend genotype-specific seeding densities, their effect of genotypes with different grain sizes on TKW needs to be evaluated carefully, since in this study neither an influence on its TKW ($r = 0.11$, $p > 0.3$) nor its protein content ($r = 0.06$, $p > 0.6$) was observed for Kleine Schwarze. This is in order

to prevent negative effects on grain quality, which is an important trait for economic lentil production. According to the economic evaluation, in sole cropped lentils, the benefit was the highest for 360 seeds per m^2 when compared to 120 seeds per m^2 but did not differ from other densities (Table 5). Although yield maximisation occurred at approximately the highest density investigated from the economic point of view, 180 seeds per m^2 would result in the same output. Nevertheless, depending on weed pressure and control measures applied, the soil conditions as well as considering any losses during germination, increasing seed density can be a valuable strategy for ensuring successful lentil cultivation. In order to show differences, scenarios established for organic and conventional conditions may help in the decision process.

4.4. Sensory Analysis

The sensory descriptive analysis showed significant differences among genotypes mainly by mouthfeel rather than by aroma or taste. Mealiness and juiciness were the only descriptors for which genotype effects reached significance, whereas the remaining descriptors showed limited between-genotype separation. The resulting sensory space of the tested lentils was therefore comparatively narrow, with texture-related sensations contributing most to the observed variation.

The sensory data should nevertheless be interpreted within the limits of the study design. The panel consisted of experienced assessors, but lentil profiling was based on two short training sessions and a single formal evaluation session without repetition. Formal within-assessor repeatability and panel reproducibility therefore could not be estimated from the present dataset. In addition, genotype-specific cooking times were used to obtain comparable firmness across the samples. This was appropriate for standardising preparation, but it may also have reduced or shifted genotype-related textural differences. Accordingly, the cluster analysis is best interpreted as an exploratory similarity structure rather than as evidence for fixed sensory classes.

From an applied perspective, the limited differentiation in aroma and taste suggests that the tested genotypes are unlikely to differ strongly in their basic flavour profile after cooking. Texture-related descriptors may nevertheless matter for specific end uses and preparation contexts. Further work should therefore combine replicated descriptive profiling with consumer testing and application-specific preparation protocols and should evaluate whether the observed mouthfeel differences remain relevant under application-specific preparation conditions.

5. Conclusions

Based on experiments conducted in the proximity of Zurich, we conclude that lentils can be grown successfully, even in humid regions of Switzerland. Neither diseases nor insects had a significant impact on yield. The biggest challenges were weed pressure and abiotic factors limiting or resulting in unstable yields among growing seasons.

Especially for lentils cultivated in autumn, the risk of crop failure can be reduced by using winter-hardy seed types. Furthermore, the earliness in flowering after autumn sowing of lentils could be advantageous, as this can protect flowering from hot/dry periods, thus also helping in stabilising the yield. Growing lentils in mixtures with oats could be an interesting approach to competing with weeds without any negative effects either on yield or on protein content. Although the sensory descriptive analysis revealed limited statistically significant differences among the lentil genotypes tested, the observed differences in juiciness and mealiness may be considered relevant for product development and consumer's preferences. Additionally, breeding could help develop new types of cultivars that cover consumers' needs and, most importantly,

would be characterised by better adaptation to abiotic stresses, thus providing yield stability. Since in the challenging season of 2016, in particular ancient and small-seeded genotypes (Kleine Schwarze, Späth's Kleine, Berglinse) were the most successful, such genotypes should carefully be evaluated—either to be grown or to be used within the breeding process.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy16101013/s1, Table S1: Cooking time of the tested lentil genotypes; Table S2: Mean sensory intensity ratings (mean ± SE) for the 12 lentil genotypes averaged across the ten assessors; Table S3: Descriptor-wise sensory statistics, model-diagnostic *p*-values, and non-parametric sensitivity analysis results; Table S4: Tukey-adjusted pairwise comparisons for descriptors with a significant global genotype effect; Table S5: Pairwise Pearson correlations among genotype mean sensory descriptors (r, 95% CI, p, and significance coding); Figure S1: Lower-triangle Pearson correlation matrix of genotype mean sensory descriptor intensities; cells show the correlation coefficient and significance markers (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Author Contributions: Conceptualization, J.H. and J.I.; methodology, A.B., J.I. and J.H.; validation, A.B., K.R., J.I. and J.H.; formal analysis, A.B., K.R. and J.I.; investigation, A.B., K.R., D.S., J.I. and J.H.; data curation, A.B., K.R., D.S., J.I. and J.H.; writing—original draft preparation, A.B., K.R. and J.I.; writing—review and editing, A.B., J.I. and J.H.; visualisation, A.B., K.R. and J.I.; supervision, J.I. and J.H.; project administration, J.H.; funding acquisition, J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from BioSuisse and Fondation Sur-la-Croix.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to thank the Agroscope field team and all the interns for their support in the technical implementation of the field experiments. We also gratefully acknowledge the Götsch family for hosting the experiments on their land and breeder D. Vlachostergios as well as the other institutions for providing seeds. We also thank BioSuisse and Fondation Sur-la-Croix for financing this study. During the preparation of this work, the authors used ChatGPT (OpenAI, GPT-4o, 2025) to assist with code development for graph creation in RStudio and to support stylistic and linguistic refinement of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of this publication. The authors would like to acknowledge the anonymous reviewers for their valuable comments and propositions which significantly contributed to improve the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

AS	autumn-sown
SS	spring-sown
TKW	thousand kernel weight

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