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Yield and Radiation Use Efficiency of Pseudocereals Compared with Oats

Ertrag und Lichtnutzungseffizienz von Pseudocerealien im Vergleich zu Hafer

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Summary

The objective of this research was to compare the capacities of pseudocereals, i.e. amaranth (*Amaranthus* spp. L.), buckwheat (*Fagopyrum esculentum* MOENCH) and quinoa (*Chenopodium quinoa* WILLD.), to absorb the incident photosynthetically active radiation (PAR) at a location in southern Germany, and to utilize absorbed PAR for dry matter production (radiation use efficiency = RUE). As a standard of comparison, oats were included in a multifactorial field experiment conducted on a loamy clay during the growing seasons in 1994 and 1995. It comprised two genotypes of each species, two plant densities and three N rates. The cumulative incident PAR available for each crop from field emergence to harvest was calculated, and the relative absorption of PAR was measured at the 4- to 6-leaf stage, at the beginning of heading, at the beginning and in the middle of grain filling. At full maturity, shoot and grain dry matter were determined. Due to the different growth periods, the cumulative incident PAR was higher for amaranth and quinoa than for buckwheat and oats. Of the incident PAR, amaranth, buckwheat, quinoa and oats absorbed on average 60, 57, 51 and 52%, respectively. In 1994, the grain yields of quinoa and amaranth reached the same level as that of oats, but the grain yield of oats was only 2.8 t ha^{-1} this year. Buckwheat produced the least amount of dry matter. The harvest index of pseudocereals was at best 0.35. Their yield response to N fertilization was similar to oats. It is concluded, that amaranth and especially quinoa are suitable as grain crops for western Europe.

Keywords: pseudocereals, oats, radiation use efficiency, yield, N fertilization

Zusammenfassung

Ziel der vorliegenden Arbeit war es, die Pseudocerealien Amarant (*Amaranthus* spp. L.), Buchweizen (*Fagopyrum esculentum* MÖNCH) und Reismelde (*Chenopodium quinoa* WILLD.) zu vergleichen hinsichtlich ihrer Fähigkeiten, die auf Pflanzenbestände auftreffende photosynthetisch aktive Strahlung (PAR) zu absorbieren und zur Ertragsbildung zu nutzen (Lichtnutzungseffizienz = RUE). Hafer war als Vergleichsfrucht in einen mehrfaktoriellen Feldversuch einbezogen, der während der Anbauperioden 1994 und 1995 in Süddeutschland auf einem lehmigen Tonboden durchgeführt wurde. Er umfasste zwei Genotypen jeder Art, je zwei Bestandesdichten und je drei N-Düngungsstufen. Es wurde die kumulierte eingestrahlte PAR für die verschiedenen Arten zwischen Feldaufgang und Ernte berechnet und die relative PAR-Absorption im 4–6-Blatt-Stadium, bei Beginn der generativen Phase, bei Beginn und zur Mitte der Kornfüllungsphase erhoben. Zur Vollreife wurden die Spross- und die Korntrockenmassen erfasst. Aufgrund unterschiedlicher Wachstumszeiträume war die PAR-Einstrahlung auf Amarant- und Reismeldebestände höher als jene auf Buchweizen- und Haferbestände. Hiervon absorbierten die Arten Amarant, Buchweizen, Reismelde und Hafer jeweils 60%, 57%, 51% bzw. 52%. Im Jahr 1994 erreichten die Kornerträge von Reismelde und Amarant das Niveau des Hafers, das in diesem Jahr bei nur 2,8 t ha^{-1} Korn-Trockenmasse lag. Buchweizen produzierte stets die geringsten Trockenmassen. Alle Pseudocerealien wiesen Ernteindizes <0,35 auf. Sie reagierten ertraglich auf die N-Düngung ähnlich wie Hafer. Es lässt sich schliessen, dass Amarant und vor allem Reismelde zur Korngutproduktion unter mitteleuropäischen Anbauverhältnissen in Frage kommen.

Schlüsselworte: Pseudocerealien, Hafer, Lichtnutzungseffizienz, Ertrag, N-Düngung

Introduction

Investigations on dry matter production of pseudocereals report shoot and grain dry matter yields (manually harvested) of 10–20 t ha^{-1} and 2.0–3.5 t ha^{-1}, respectively, for amaranth (JAMRISKA 1990, LAZANYI et al. 1990, AUFHAMMER et al. 1995a, b, PIHA 1995, WEGERLE & ZELLER 1995, KAUL et al. 1996). For buckwheat, shoot yields of 5–12 t ha^{-1} and grain yields of 1.2–3.0 t ha^{-1} were observed (GUBBELS 1977, FAROOQ & TAHIR 1987, KAIFEZ-BOGATAJ 1987, AUFHAMMER & KÜBLER 1991, AUFHAMMER et al. 1994, 1995b). Corresponding figures for quinoa are 9–18 t ha^{-1} of shoot and 2.5–3.5 t ha^{-1} of grain yield (CARBONE 1986, AUFHAMMER et al. 1995b). Reported harvest indices ranged from 0.10–0.30 for amaranth, 0.28–0.35 for buckwheat and around 0.35 for quinoa.

Absorption of PAR by crops is a prerequisite for dry matter production. The cumulative incident PAR is the maximum amount of radiation available for dry matter production. The relative PAR absorption depends – among others – on leaf area and leaf orientation (MONTEITH & ELSTON 1983). For amaranth, maximum leaf area index (LAI) values reported are between 5.2 and 6.8. Under these conditions, the relative PAR absorption is close to 100% (FASHEUN & IBE 1986, HAND et al. 1993). For buckwheat crops, LAI values between 2.8 and 7.6 were observed depending on growth conditions (KAIFEZ-BOGATAJ & KNAVS 1985, KAIFEZ-BOGATAJ 1989, TAHIR & FAROOQ 1990). To our knowledge, the leaf area development and relative PAR absorption of quinoa crops have not yet been studied. Also, no investigations were found reporting radiation use efficiencies (RUE) of pseudocereals.

At a particular location, the cumulative incident PAR depends on the weather conditions and the growth period of a crop. It can be varied by sowing date and the choice of cultivars with different rates of development. The relative PAR absorption is generally higher with more planophile oriented leaves of dicotyledonous pseudocereals than with erectophile leaves of cereals, but the LAI of the crop has to be considered. Both can be improved by more dense crops. Additionally, high chlorophyll concentrations in the canopy increase PAR absorption. Nitrogen is a main constituent of chlorophyll and it is also part of enzymes involved in photosynthesis. Thus it might increase PAR absorption and RUE.

The present study compares the abilities of amaranth, buckwheat and quinoa crops to produce dry matter, particularly grain yield, during two vegetation periods under the climatic conditions in western Europe. At the same time, the effects of main factors of crop husbandry, i.e. genotype, crop density and N rate, on yield were investigated. Subsequently, we will contrast differences in yield with those in cumulative incident PAR available for the different crops, in PAR absorbed, in RUE and in harvest index. Besides the pseudocereals, which are comparatively unadapted to cool and wet conditions, the experiments included adapted cultivars of oat as a standard for comparison. Among cereal crops, oats have a growth period and a nutritional grain quality most similar to those of the pseudocereals. The aim of the study was to explore whether the different factors of radiation use by crops can help to explain differences in yield production.

Material and Methods

A multifactorial field experiment with four replicates in a randomized complete block design with a split-plot arrangement (Tab. 1) was conducted on the experimental farm "Ihinger Hof" in southern Germany (49° N, 9° E, avg. temperature 8.0 °C, precipitation 690 mm year^{-1}, 480 m a.s.l.) in the years 1994 and 1995. The climatic conditions during the experiments are indicated in Tab. 2. The three pseudocereal species amaranth, buckwheat and quinoa, and oats were sown in main plots. Each species was represented by two genotypes and grown at two densities and three N rates. With reference to the different plant density levels for the species, buckwheat and oat crops were sown in rows spaced 12 cm apart, whereas amaranth and quinoa were sown in rows spaced 30 cm apart. The size of the individual plots was 4 × 6 m^2.

Tab. 1: Factorial experimental design

Faktorielle Versuchsanlage

Species Genotype (origin)	Crop density (m^{-2}) sown	Crop density (m^{-2}) emerged[1)]	N rate[2)] (kg ha^{-1})
Amaranth			
K 343 (USA)	30	23 (D1)	0 (N0)
K 432 (USA)	90	70 (D2)	80[3)] (N1)
			80+40[4)] (N2)
Buckwheat			
Hruszowska (Poland)	150	141 (D1)	0 (N0)
Prego (D)	450	372 (D2)	30[3)] (N1)
			30+30[4)] (N2)
Quinoa			
Faro (Chile)	30	23 (D1)	0 (N0)
Cochabamba (USA)	90	46 (D2)	80[3)] (N1)
			80+40[4)] (N2)
Oats			
Jumbo, hulled (D)	120	104 (D1)	0 (N0)
Salomon, hull-less (D)	360	290 (D2)	80[3)] (N1)
			80+40[4)] (N2)

1) means across two years, two genotypes, three N rates
2) N fertilizer NH_4NO_3+$CaCO_3$, NO_3-N supply (0 to 90 cm soil depth) in spring 1994: 38 kg ha^{-1}, 1995: 58 kg ha^{-1}
3) 4- to 6-leaf stage
4) 4- to 6-leaf stage + beginning of heading

Tab. 2: Climatic conditions (mean air temperatures and monthly rainfall)

Klimatische Versuchsbedingungen (mittlere Lufttemperaturen und Niederschlagssummen)

Month	1994 °C	1994 mm	1995 °C	1995 mm
March	7.5	44	2.7	71
April	6.8	91	8.3	50
May	12.4	113	11.8	94
June	15.8	82	13.5	77
July	20.0	115	19.2	96
August	17.4	57	16.6	78
September	13.1	80	10.9	75
October	7.8	18	11.5	37

The pseudocereal genotypes were selected on the basis of former experiments at the same location. Both amaranth genotypes are crosses between *A. hypochondriacus* and *A. hybridus* developed at the Rodale Research Center, Kutztown, PA (WEBER et al. 1990). K 343 is tall growing, while K 432 is a semi-dwarf genotype. The German buckwheat cv. Prego has a shorter flowering period than the Polish cv. Hruszowska. This promised less branching and a more homogeneous ripening of cv. Prego. Both quinoa genotypes are of "sea level" type. They should branch only little and flower early under central European conditions (CARBONE 1986). The oat cultivars were chosen from the German recommendation list, including one hull-less (naked) oat genotype.

The purpose of the two specific crop density levels was to compare populations with different branching intensities. This should result in crop canopies with different capabilities for PAR absorption. Because the size of individual plants differs considerably among species, plant density levels were not the same for all species.

Without any fertilizer supply (N0), crops could only take up N mineralized from the soil. A fertilization during the 4- to 6-leaf stage (N1) should have supported the development of leaf area and of flower primordia. An additional fertilization at the beginning of heading (N2) aimed at an extended leaf area duration and thus an improvement of grain yield. The N rates for buckwheat were chosen lower than for other species considering its comparatively short growth period and in order to prevent lodging.

Daily incident global radiation was logged by a portable weather station (Monitor Sensors, Australia) adjacent to the experiments (Tab. 3), and PAR was calculated by multiplying global radiation values with 0.5 (SZEICZ 1974). The cumulative incident PAR was calculated for each individual crop as the sum of the daily recorded PAR between field emergence and final harvest.

After field emergence (date 1, for individual dates cf. Fig. 1), the relative PAR absorption was measured on four

Tab. 3: Experimental traits, measured and calculated parameters

Untersuchungsmerkmale, gemessene und berechnete Grössen

Traits	Unit	Methods of measurements	Calculations
Daily incident photosynthetic active radiation (PAR)	MJ m^{-2} d^{-1}	Global radiation sensor	Global radiation × 0.5 (SZEICZ 1974)
Cumulative incident PAR	MJ m^{-2}	–	Sum of daily PAR from emergence to harvest
Relative PAR absorption	–	Incident PAR above (I_0) and below (I) canopy	$1 - (I \times I_0^{-1})$
Cumulative PAR absorption	MJ m^{-2}	–	Sum of daily incident PAR × rel. PAR absorption from emergence to harvest[1)]
Mean relative PAR absorption	–	–	Cum. PAR absorption × cum. incident PAR^{-1}
Shoot dry matter	g m^{-2}	Plant samples	–
Grain yield	g m^{-2}	Threshed from plant samples	–
Radiation use efficiency (RUE)	g MJ^{-1}	–	Shoot dry matter × cum. PAR $absorption^{-1}$
Harvest index	–	–	Grain yield × shoot dry $matter^{-1}$

[1)] Daily rel. PAR absorption from linear interpolation between sampling dates

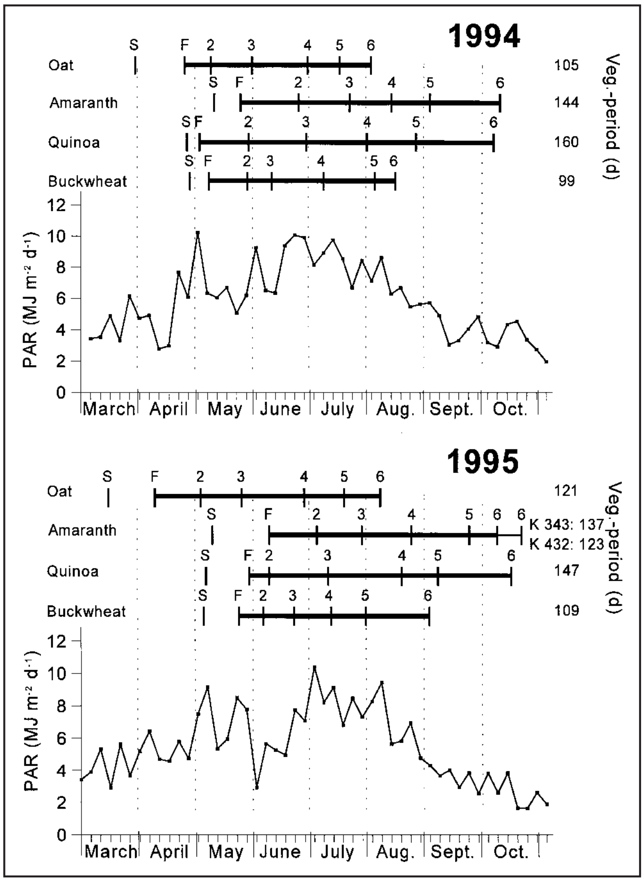

Fig. 1: Daily incident PAR (means of five days), crop development and sampling dates (S: sowing date, F: field emergence, 2 to 5: sampling dates, 6: final harvest at full maturity)

Täglich eingestrahlte PAR (Pentaden-Mittelwerte), Stadien der Pflanzenentwicklung und Probenahmetermine (S: Saat, F: Feldaufgang, 2–5: Probenahmetermine, 6: Ernte bei Vollreife)

dates: at the 4- to 6-leaf stage, just before the first fertilization (date 2), at beginning of heading, just before the second fertilization (date 3), at beginning of grain filling (date 4) and in mid grain filling (date 5). For each plot, the relation between instantaneous measurements of incident PAR by a point sensor just above the canopy and a line sensor on the soil surface below the canopy was determined in three replicates. Both sensors were from LICOR Inc. (USA). The line sensor on the soil was aligned north to south crosswise with the plant rows. Measurements were always conducted between 11.00 and 13.00 h MET, thus the change of the solar angle between sampling dates is negligible. The method ignores the reflection of radiation by green canopies, but this can be estimated at less than 5% of the irradiance (HAMMER & VANDERLIP 1989).

Relative PAR absorption was assumed to be 0 at field emergence and at final harvest. With this assumption, the relative PAR absorption was estimated for each day by linear interpolation between sampling dates and multiplied with the daily incident PAR to calculate the daily PAR absorption.

At full maturity (date 6, final harvest), plant shoots were sampled and threshed by a stationary thresher for grain yield. The sampling areas were 1.35 m^2 for amaranth and quinoa, and 0.50 m^2 for buckwheat and oats. The indicated yield figures are 100% dry matter.

Analyses of variance of the experiment, including year effects, were performed according to the split-plot design using the ANOVA procedure from SAS (SAS INST. 1987). Although variances among species were not always homogeneous, we chose to perform the analyses of variance with species as a factor in order to get a statistical indication of differences among species. The effect of genotypes was considered as nested within species. Means were separated by Fisher's LSD, when F-tests indicated significant effects ($P < 0.01$) of treatments.

Results

The development of the different crops in relation to the incident PAR during the vegetation periods in 1994 and 1995 is depicted in Fig. 1. The individual parts of the vegetation periods utilized by the species varied considerably, mainly because of their different temperature requirements. Oats started and completed development earlier than pseudocereals. Buckwheat grew only 99 to 109 d from field emergence to maturity, while amaranth and quinoa required up to 160 d.

The results section is concentrated on the differences between species and their interactions with crop husbandry, and we consider only effects with $P < 0.01$. Under these provisions, the analyses of variance of dry matter production showed that considerable variance was caused by the species × year and the species × N rate interactions (Tab. 4). For grain yield, the interaction genotype × year has to be considered. Effects of crop density were comparatively small and did not influence grain yield.

In both years, buckwheat reached only about half the shoot and grain dry matter of oats (Tab. 5). In 1994, amaranth and quinoa produced about the same amount of shoot and grain dry matter as oats, however the average grain yield of oats was only 2.8 t ha^{-1}. In 1995, the shoot dry matter of quinoa and the grain yield of amaranth and quinoa were less than those of oats. Differences in grain yield between genotypes were observed with oats. The yield of the hull-less cv. Salomon was substantially lower than that of the hulled cv. Jumbo.

During the comparatively long development of amaranth and quinoa, the cumulative incident PAR was only in 1994 substantially higher than that during the shorter development of buckwheat and oats. In 1995, incident PAR was generally low, and the differences between species in growth period were smaller. Thus differences among species in incident PAR were also small.

In 1994, quinoa's mean relative PAR absorption was low. Although in 1995 the relative PAR absorption of all pseudocereals was higher than that of oats, only amaranth and quinoa had a significantly higher cumulative PAR absorption.

In 1994 the RUE of amaranth and quinoa was similar to that of oats, but in 1995 the species differed substantially with significant differences between oats, amaranth and quinoa. Buckwheat utilized the absorbed PAR with the lowest efficiency in both years.

The harvest indices of the pseudocereal crops, especially those of amaranth, were lower than those of the oat cv. Jumbo, while the hull-less oat cv. Salomon was on the same low level as the pseudocereals. In 1994, the harvest index of the amaranth genotype K 432 was higher than that of K 343, but this result was not confirmed in 1995.

The shoot dry matter of all crops increased due to a single N dressing (N1) compared with no N fertilizer (N0), but only amaranth crops responded to an additional N rate (N2) with additional shoot dry matter (Tab. 6). None of the species showed an increase in grain yield due to N fertilization beyond a single application, and buckwheat grain yield did not respond to N fertilization at all.

In general, with a single N application the relative and the cumulative PAR absorption were higher than without N, but the additional late dressings had no effect. Thus the positive reaction of amaranth in shoot dry matter on the highest N level indicates an increased RUE which is confirmed by the RUE results. RUE of oats was enhanced by N fertilization only on level N1, whereas RUE of buckwheat and quinoa was hardly affected by N rate at all.

The harvest index responded to fertilizer N only with buckwheat. It decreased with increasing N rates.

Tab. 4: Factorial[1)] analysis of variance (selected mean squares) of shoot dry matter and grain yield

Faktorielle Varianzanalyse (ausgewählte MQ-Werte) von Sprosstrockenmasse und Kornertrag

Source of variance	df	Shoot dry matter	Grain yield
Year (Y)	1	196	497
Error	6	509	91
Species (S)	3	70547***	7366***
Y x S	3	4667**	1973***
Error	18	729	105
Genotype (G(S))	4	4613***	1636***
N rate (N)	2	40108***	2019***
Density (D)	1	631	12
Y × G(S)	4	854	482***
Y × S × N	6	162	32
Y × G(S) × N	8	488	17
Y × S x D	3	626	13
Y × G(S) × D	4	336	20
Y × S × N × D	6	435	18
Y × G(S) × N × D	8	0	12
S × N	6	2769***	412***
G(S) × N	8	516	54
S × D	3	1068**	15
G(S) × D	4	0	34
S × N × D	6	86	22
G(S) × N × D	8	290	23
Residual	264	260	40

, * Significant at the 0.01 and 0.001 probability levels, respectively

1) Factorial is a split-split-plot design with year as main plots, species on subplots, all other factors randomized within species and genotype nested within species

Discussion

We compared three dicotyledonous pseudocereals with the monocotyledonous cereal oats. The common purpose of the cultivation of all these crops is the production of starchy grains utilizable for human nutrition. During the investigations presented and under the described growing conditions, amaranth and quinoa, but not buckwheat, were able to produce grain yields on the same yield level as the hull-less oat cv. Salomon. This level, however, was below 3 t ha^{-1}. It has to be recognized, that the yield of naked oat genotypes increases by about 40% if the hulls were harvested (VALENTINE 1990). The pseudocereals' reactions to N fertilization in PAR absorption, RUE and harvest index were similar to those of oats.

Significant effects of crop density were missing. For amaranth and quinoa this can be explained by the extremely variable field emergence of these small-seeded species (data not shown). The effects of sowing density were small within the limits tested during our investigations. Presumably much higher plant densities could be advantageous providing that plant distribution is optimized and dry matter distribution, i.e. the harvest index, is not adversely affected.

The species differ significantly in morphological and physiological characters and in environmental demands. Individual temperature and daylength requirements determined the time of sowing and emergence. Thus the cumulative incident PAR was different for each crop. Oat crops were earliest in establishing PAR absorbing canopies. This was due to the low minimum temperature for

Tab. 5: Characters determining PAR utilization and dry matter production of pseudocereals and oats as influenced by year, species and genotype

Merkmale zur Charakterisierung von PAR-Nutzung und Trockenmasseproduktion durch Pseudocerealien und Hafer in Abhängigkeit von Jahr, Art und Genotyp

Species	Amaranth				Buckwheat				Quinoa				Oats				
Year	1994		1995		1994		1995		1994		1995		1994		1995		
Genotype	K343	K432	K343	K432	Hrus.	Prego	Hrus.	Prego	Faro	Coch.	Faro	Coch.	Jumbo	Salo.	Jumbo	Salo.	$LSD_{0.01}$
Cum. incident PAR ($MJ\ m^{-2}$)	964		735		830		726		1058		821		830		820		–
Cum. PAR absorption ($MJ\ m^{-2}$)	589		428		462		396		499		445		476		380		46.6[1])
Mean rel. PAR absorption	0.61		0.58		0.59		0.55		0.47		0.54		0.57		0.46		0.053[1])
Shoot dry matter ($g\ m^{-2}$)	1109		1161		546		472		961		875		943		1154		165.8[1])
RUE ($g\ MJ^{-1}$)	2.44		2.83		1.33		1.86		2.33		2.30		2.39		3.52		0.296[1])
Grain yield ($g\ m^{-2}$)	227	283	240	213	146	138	156	139	302	305	241	264	323	240	556	312	51.7[2])
Harvest index	0.19	0.31	0.17	0.20	0.29	0.25	0.32	0.34	0.30	0.33	0.28	0.31	0.35	0.25	0.48	0.27	0.049[2])

[1]) LSD for interaction year x species
[2]) LSD for interaction year x genotype (species)

Tab. 6: Characters determining PAR utilization and dry matter production of pseudocereals and oats as influenced by species and N rate

Merkmale zur Charakterisierung von PAR-Nutzung und Trockenmasseproduktion durch Pseudocerealien und Hafer in Abhängigkeit von Art und N-Düngung

Species	Amaranth			Buckwheat			Quinoa			Oats			
N rate	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2	$LSD_{0.01}$
Cum. incident PAR ($MJ\ m^{-2}$)		850			778			940			825		–
Cum. PAR absorption ($MJ\ m^{-2}$)	489	534	530	379	449	460	368	509	524	377	450	457	19.2
Mean rel. PAR absorption	0.57	0.61	0.61	0.50	0.59	0.61	0.40	0.55	0.56	0.46	0.55	0.55	0.023
Shoot dry matter ($g\ m^{-2}$)	924	1123	1347	415	545	566	586	1023	1102	828	1176	1142	112.0
RUE ($g\ MJ^{-1}$)	2.48	2.51	2.85	1.44	1.64	1.71	2.21	2.27	2.45	2.57	3.27	3.02	0.331
Grain yield ($g\ m^{-2}$)	208	250	263	140	151	143	178	301	339	300	408	366	43.7
Harvest index	0.23	0.24	0.20	0.35	0.29	0.26	0.31	0.30	0.31	0.35	0.35	0.32	0.042

[1]) LSD for interaction species × N rate

germination of oats and the – although limited – frost resistance. The need of the pseudocereals for a frost-free growth period with significantly higher temperatures delayed their crop establishment for several weeks, also depending on year. Shoot dry matter production of buckwheat and oats ended at about the same date, while the dry matter production of quinoa and amaranth continued much longer. Because of their high temperature requirements, the pseudocereals were less adapted to the time course of radiation at our European site than the spring sown cereal oat. The long growth periods of amaranth and quinoa compensated only to some extent for the decreasing incident PAR.

During their development from emergence to harvest, amaranth and buckwheat absorbed on average 55 to 61% of the incident PAR (Tab. 5). Contrasting to these large-leaved crops, quinoa developed leaves with small blades and petioles that shaded each other and died off early from the stem base to the top. The growth period of quinoa was longer than that of oats, but the mean relative PAR absorption was on the level of oats at about 50%.

Amaranth was most successful in absorbing much PAR and transforming it into biomass, i.e. had the highest RUE, but was least efficient in relative grain production, i.e. produced the lowest harvest index. Quinoa and buckwheat used relatively more dry matter for grain production than amaranth, but their cumulative PAR absorption and the produced shoot biomasses were smaller. For buckwheat, the short growth period and the low RUE were crucial factors that would be difficult to improve agronomically. Quinoa crops with an adapted plant density should be able to produce 4 to 5 t ha^{-1} of dry grain similar to oats under our conditions (LEE et al. 1996).

Conclusions

During the whole growth period from emergence to harvest, the mean relative PAR absorption of pseudocereals and oats was low, reaching only 0.46 to 0.61. This trait needs to be improved not only for a higher biomass productivity but also for a better weed suppression, which is a separate problem with pseudocereal crops.

Amaranth and buckwheat require comparatively high soil temperatures for germination. Due to the long growth period, the late sowing dates make maturity uncertain, especially for amaranth. The selection of earlier ripening, cool-tolerant genotypes would be helpful in this case.

For amaranth, genetic variability in harvest index is available (KAUL et al. 1996). Hence breeding efforts to improve this trait might be promising, although the present investigations showed a considerable genotype × environment interaction. Additionally, the homogeneity of crop development should be improved by establishing dense, less branching crops. Thus the comparatively high PAR absorption ability and RUE of amaranth could be better used for grain production.

Preferably with quinoa, further investigations should be made to improve PAR absorption and RUE by additional N dressings. This could, however, delay ripening and affect grain harvestability.

Except in some eastern European regions, pseudocereals play no role yet in European crop production. However, if adapted cultivars and site-specific production techniques were developed, the species, especially quinoa, offer a potential source of raw materials for the production of healthy food supplies (AUFHAMMER et al. 1995b).

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