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RESEARCH

Intercropping traditional pea varieties with faba bean produces grain yields similar to pure stands of modern varieties in organic agriculture

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Abstract Although being a historical farming practise, little research has been performed on intercropping pea with faba bean, and no study has previously tested traditional varieties in this species combination. To evaluate the influence of variety and seeding ratio on grain yield in pea-faba bean intercropping, a field experiment was conducted over three years (2021–2023) under organic management in southern Sweden. The experiment included a set of three faba bean varieties, and nine traditional and one modern pea variety. Total yield (sum of both species) of the intercrops with traditional pea varieties varied from around 0.44 to 4.9 t ha^{-1} across all years and treatments, and several of the intercrop combinations were as productive as pure stands of modern varieties (both species). When compared in intercropping, some traditional pea varieties produced higher pea yield than the modern variety. There was a big difference among pea varieties in their competitiveness toward the intercropped faba bean. By using traditional varieties, it was possible to find matching maturity times and segregating seed sizes between the two species. Intercropping did generally not influence time to pod maturity or seed size. Traditional pea varieties suffered from severe lodging in pure stands and gained improved standing ability when intercropped with faba bean. This study has shown that intercropping pea with faba bean can facilitate the production of traditional pea varieties that lack proper standing ability on their own; however, different varieties require different seeding ratios for optimal performance.

Keywords *Vicia faba* · *Pisum sativum* · Mixed cropping · Grain legumes · Heritage varieties · Landraces

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Introduction

Intercropping of different plant species, also referred to as companion cropping, mixed cropping, or polyculture, is an agroecological practise that can contribute to increased productivity, higher yield stability, reduced input levels, and fewer weed control measures (Jensen et al. 2015, 2020; Raseduzzaman and Jensen 2017)—all relevant aspects for improving organic agriculture. There are several ways of designing intercrop-systems, including relay-, strip-, row-, within-row-, and mixed intercropping (Andrews and Kassam 1976; Lithourgidis et al. 2011). The seeding rates can either be designed in a replacement or additive manner, or a mixture of the two (Raseduzzaman and Jensen 2017). In replacement designs, the seeding rates of both crops are reduced so that the total amount adds up to 100% of the recommended pure stand seeding rates. Additive designs increase the total seeding rate above the recommended level for cultivation in pure stands. Interaction between species needs to be considered for optimal intercropping, and can be described with the help of the 4C approach, entailing *competition*, *complementarity*, *cooperation (facilitation)*, and *compensation* (Justes et al. 2021). Further, intercropping can be designed with perennial, bi-annual and annual plants, in agroforestry systems as well as horticultural and arable production (Jensen et al. 2015). Studies targeting the latter commonly combine non-legumes (often cereals) with legumes (Raseduzzaman and Jensen 2017).

Legumes can have symbiotic relationships with bacteria that fix atmospheric nitrogen and therefore add nitrogen to the cropping system. After legume cultivation residual nitrogen is left in the soil to the subsequent crop, however, the amount depends on several factors related to species, environmental conditions, genetics, harvest time, handling of crop residues (*i.e.* incorporation or removal), and management practises (Peoples et al. 2009; Jensen et al. 2010). Unfortunately, many commonly cultivated legumes are sensitive to soil borne diseases, and faba bean and pea are for instance discouraged to grow on the same land more often than every eight years in Swedish organic production (Holstmark 2022b). To optimise the benefits of both legumes and intercropping in the limited time–space the legume has in the crop rotation, intercropping of two different legumes can be an interesting possibility, and has been mentioned to be a promising prospect that needs further research attention (Mikić et al. 2015).

In some regions in Sweden, where legume cultivation was particularly intense (Bohuslän and Halland county), intercropping pea with faba bean was an established cultivation method before modernisation of agriculture (Böving 1911; Dannfelt 1901; Leino et al. 2023). Usually, the combination consisted of faba bean and grey pea (Fröodlingens fröhandel 1904), and a few landraces with known historical application in this species intercrop-combination still exist (Leino et al. 2023). Although being a historical farming practise, only a few studies have previously examined intercropping of pea with faba bean in a temperate climate (Stelling 1997; Živanov et al. 2018). These studies, like many other intercropping studies, were mainly using varieties developed in plant breeding programmes aimed towards cultivation in pure stands. Therefore, there is a need to explore how faba bean and pea varieties representing a broader phenotypic diversity, including traits mainly associated with traditional varieties, performs in intercropping systems. Matching suitable faba bean and pea varieties with complementary and facilitating phenotypes might be a way to increase grain yield in organic farming. Further, intercropping has the potential to reduce lodging and facilitate the production of traditional pea varieties associated with interesting cultural-, quality- and culinary attributes (Westling et al. 2019). Such attributes may increase consumer demand for organic and diversified produce (Chable et al. 2020), as well as locally produced plant based protein sources as climate smart alternatives to meat (Röös et al. 2020).

Traditional crop varieties are described by Preston et al. (2012) as an overarching category of varieties that are not developed with modern plant breeding techniques. The category includes subcategories such as heirloom varieties, garden varieties, landraces, heritage varieties, and farmers' varieties (Preston et al. 2012). It is complicated to apply strict definitions to a reality that is as dynamic as plant varieties, where some may fall into several categories depending on use and management. Especially pea varieties can be very diverse, and has been used in many different production systems (*i.e.* garden, forage, and grain production, as well as pure stand and intercropping). In 1978 the first semi-leafless (*i.e.* leaves replaced with tendrils—often referred to as *afila*) pea variety was introduced (Ambrose 2004), and became the dominant type of pea in arable production (Tayeh et al. 2024). The here presented study explore intercropping of faba bean and pea varieties with a broad phenotypic diversity, and primarily differentiate between traditional crop varieties and modern varieties. The traditional crop varieties included in this study are subcategorised in old varieties, including a blend of heritage and heirloom varieties (Preston et al. 2012), and landraces (Camacho Villa et al. 2005).

The aim of this study was to evaluate the effect of variety choice and seeding ratio on grain yield and crop interactions relevant for grain production in organic intercropping of faba bean (three varieties) and pea (ten varieties) with diverse above ground plant architectures.

Material and methods

Site and weather conditions

The field experiments were conducted during three years (2021–2023) at the Swedish University of Agricultural Sciences (SLU), campus Alnarp, in the south of Sweden. The first experimental field (coordinates: 55.6507 13.0754, 55.6508, 13.0761) was used both 2021 and 2022 (different parts of the field), while the second (coordinates: 55.6607, 13.0798) was used during 2023. Yearly weather data (Table 1) was retrieved from the SITES (Swedish Infrastructure for Ecosystem Science) data portal (Lönnstorp Research Station 2022, 2023, and 2024) for their weather station located at the Lönnstorp field research station, which is approximately 2.5 km from the field site used in 2021 and 2022, and 1.5 km from the field site used in 2023. The 30-year average (1991–2020) (Table 1) values were retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) weather station "Malmö A" (SMHI 2021) which is approximately 10 km from the field sites. Clear deviations from the 30 year averages are reduced precipitation in June 2021 and May and June 2023 (Table 1). This caused two different types of drought, with 2023 being more severe due to a longer period of ceased precipitation. Soil samples for basic chemical soil characteristic (Table 2) were analysed by Agrilab AB. The samples were taken from soil mixtures based on 10 subsamples collected from evenly distributed points across the experimental fields, sampled at a depth of 0–30 cm.

Experimental design and agronomic management

In 2021 the preceding crops were (starting with the latest) spring barley, ley, ley, and ley; in 2022 spring wheat, spring barley, ley, and ley; in 2023 spring wheat, ley, ley, and oats with seeded ley. Both field sites were certified organic (Regulation (EU) 2018/848), and no chemicals, fertilisers or irrigation were applied during the experiment. Sowing dates were 16th (2021), 12th (2022), and

Table 1 Temperature and precipitation data for the growing seasons of the three years of field experiments. Yearly data is from the nearby field station Lönnstorp while 30-year average (ave. 30) is from the SMHI weather station Malmö A, approximately 10 km from the experimental sites

	Average temp. (°C)				Max temp. (°C)			Min temp. (°C)			Precipitation (mm)			
Month	2021	2022	2023	ave. 30	2021	2022	2023	2021	2022	2023	2021	2022	2023	ave. 30
March	4	3	4	3	17	14	12	−5	−8	0	35	0	69	37
April	6	7	7	8	18	18	18	−3	−7	3	25	40	20	30
May	11	12	13	12	22	23	25	0	2	8	66	54	9	39
June	17	16	17	16	31	29	27	5	6	11	3	34	16	61
July	20	18	17	18	31	32	27	9	7	14	47	35	35	58
August	16	19	17	18	26	33	25	5	6	14	66	40	40	71

Table 2 Basic chemical characteristics of the top soil (0–30 cm) of the experimental sites. Available nutrients were measured after extraction in ammonium lactate (0.1 mol l^{-1}) and acetic acid (0.4 mol l^{-1}), and total nutrients after extraction with HCl (2 mol l^{-1}), and reported in mg per 100 g dry soil

Year	pH	Available P (mg 100 g^{-1})	Available K (mg 100 g^{-1})	Available Ca (mg 100 g^{-1})	Total P (mg 100 g^{-1})	Total K (mg 100 g^{-1})	Organic matter (%)	Clay (%)	Silt (%)	Sand (%)
2021	7.4	14.7	8.6	1691	58.6	90.1	4.6	14	26	55
2022	7.6	16.8	6.8	2721	75.0	81.2	7.2	18	25	50
2023	6.4	10.6	7.6	305	51.1	98.5	2.8	19	25	53

19th (2023) of April. The experiment was fenced, and after sowing the field was covered with a horticultural fleece for 23 (2021), 24 (2022) and 20 (2023) days to protect against animals. The experiments were designed in completely randomised blocks replicated three times. Each plot was 2 × 3 m in size, sown with 16 rows (12 cm apart).

The sowing was conducted with an F.Walter-H. Wintersteiger Öyjord plot drill with a sowing depth of 5–8 cm. The seeds of both species were mixed in the same bag before sowing—generating a random distribution in each row. Germination tests were conducted each year before sowing to adjust the seeding ratios accordingly. Crop establishment was assessed to ensure satisfactory emergence. The distance between the plots (two meters in all directions) and the surrounding border of the field (two meters wide) was cultivated with spring-sown winter rye, sown at the same time as the experimental plots. Anti-bird nets were used during the seed maturation period to protect the plots from pigeons in 2022 and 2023, but not in 2021 (resulting in pigeon damages in some plots, see discussion).

Varieties and treatments

The trials included ten different pea and three different faba bean varieties (Table 3). Nine of the ten pea varieties were traditional varieties, of which six were landraces and three old varieties with local origin (Sweden or neighbouring countries). These varieties were selected to represent widely different aboveground plant architectures (Table 3). One modern semi-leafless pea variety, Ingrid, was included as a control representing a typical pea variety contemporarily used in local organic farming. For faba bean the variety Birgit was used as the modern control based on the same criterion. In addition, faba bean varieties Kontu and Solberga were also included in the experiment. The former being a Finnish variety with a small stature and early maturation, and the latter a Swedish landrace traditionally intercropped with pea (a pea landrace also named Solberga that is included in the experiment as well). Seed of the different varieties were gathered from various sources including farmers, seed savers, gene banks and companies. Some seed were produced conventionally but aimed for organic application (*i.e.* according to standards required for using conventional seed in organic production), while most were produced under certified organic conditions.

The first trial year (2021) included 20 treatments of which 6 were discontinued (and not presented in this article). In 2022 and 2023, 12 new treatments were added to further explore different seeding ratios and increase the representation of different phenotypes

Table 3 List of varieties used in the study including variety type and characteristics of their aboveground plant architecture

Variety name	Species	Variety type	Leaf type	Growth habit	Stem length (m)[1]
Solberga[2]	*Pisum sativum*	Landrace	Leafy	Vining	2.0–3.0
Brattebräcka	*Pisum sativum*	Landrace	Leafy	Vining	2.0–3.0
Maglaby	*Pisum sativum*	Landrace	Leafy	Vining	1.5–2.0
Rustica	*Pisum sativum*	Old variety	Leafy	Vining	1.5–2.0
Ringeriksert	*Pisum sativum*	Landrace	Leafy	Vining	1.5–2.0
Östgöta gulärt	*Pisum sativum*	Landrace	Leafy	Vining	1.5–2.0
Bjurholms småärt	*Pisum sativum*	Landrace	Leafy	Vining	1.0–1.5
Ingrid[3]	*Pisum sativum*	Modern variety	Semi-leafless	Erect	0.6–1.1
Stäme	*Pisum sativum*	Old variety	Leafy	Erect	0.4–0.7
Concordia	*Pisum sativum*	Old variety	Leafy	Erect	0.4–0.8
Birgit[3]	*Vicia faba*	Modern variety			0.6–1.2
Kontu	*Vicia faba*	Modern variety			0.4–1.0
Solberga[2]	*Vicia faba*	Landrace			0.6–1.3

[1]According to available variety descriptions and un-published pre-studies

[2]Historically used in faba bean-pea intercropping (note that both the pea and the faba bean variety have the same name)

[3]Modern control, commonly used in contemporary organic farming in Sweden

of traditional varieties (that were made available through seed multiplication in 2021), summing up to 26 treatments in total (Table 4). All faba bean and four pea varieties were included as pure stands, the latter including the modern control Ingrid, the short and erect variety Stäme, the long and vining landrace Maglaby and very long and vining landrace Solberga (all further described in Table 3). The impact of intercropping with different faba bean varieties were tested on these four pea varieties, of which the first three were tested with Birgit and Kontu, while Solberga (pea) was tested with Birgit and Solberga (faba bean).

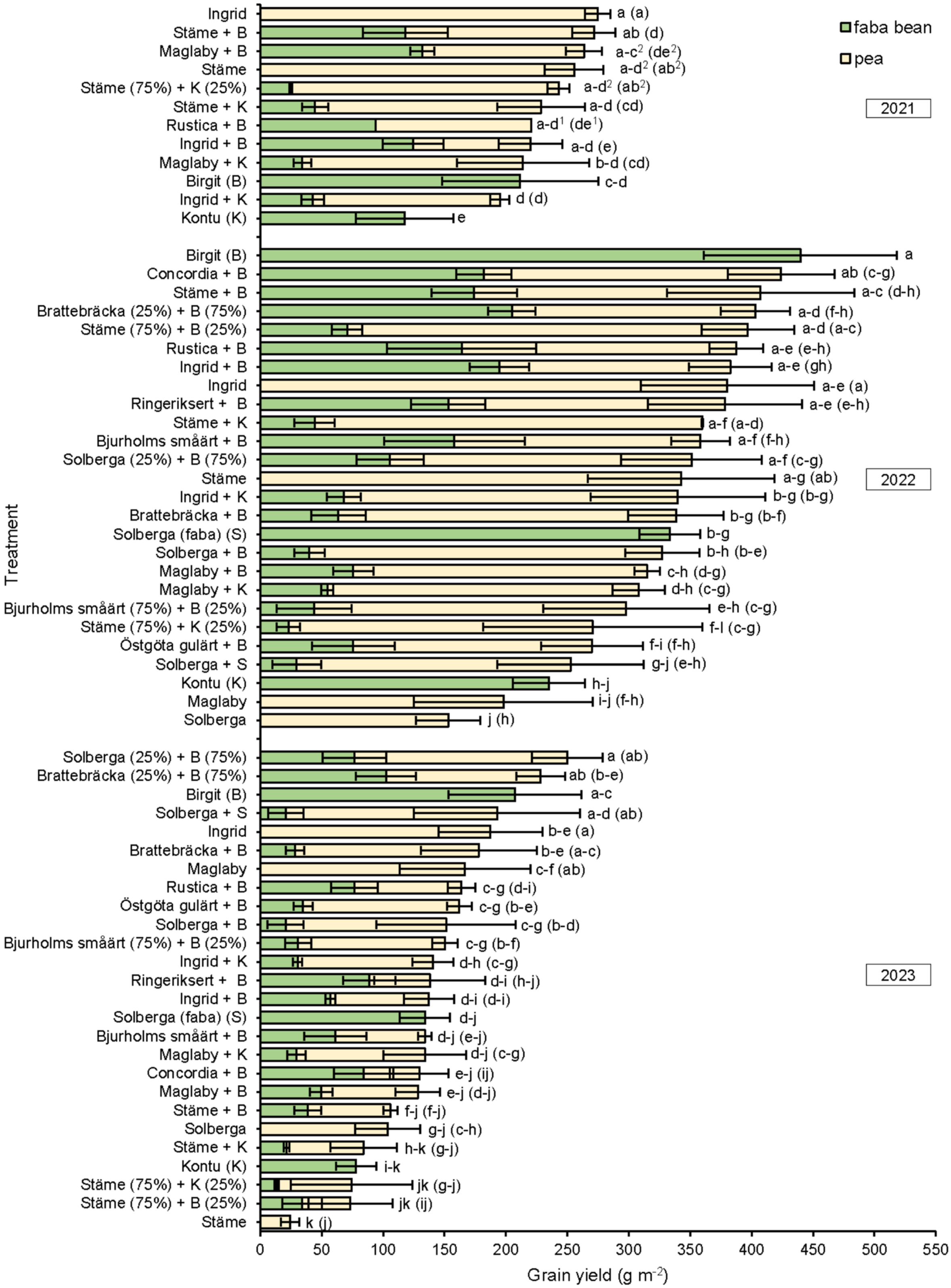
In addition to the 50:50 seeding ratio, alternative ratios were included with the pea varieties Stäme, Bjurholms småärt, Brattebräcka and Solberga with either an increase (75:25; Stäme, Bjurholms småärt) or decrease (25:75; Brattebräcka, Solberga) in the proportion of pea relative to faba bean. The target seeding rates in sole crops (100%) were 100 plants m^{-2} for the pea and 50 plants m^{-2} for the faba bean. The intercropping treatments had a replacement design based on those pure stand rates. Alternated seeding ratios of 25% and 75% therefore translates to 25 and 75 plants m^{-2} for pea, and 12.5 and 37.5 plants m^{-2} for faba bean.

Table 4 List of treatments included in the study

Pea variety	Faba bean variety	Seed ratio	Years included
	Birgit	100	2021–2023
	Kontu	100	2021–2023
	Solberga	100	2022–2023
Bjurholms småärt	Birgit	50:50	2022–2023
Bjurholms småärt	Birgit	75:25	2022–2023
Brattebräcka	Birgit	50:50	2022–2023
Brattebräcka	Birgit	25:75	2022–2023
Solberga	Birgit	50:50	2021–2023
Solberga	Birgit	25:75	2022–2023
Solberga	Solberga	50:50	2022–2023
Solberga		100	2021–2023
Maglaby	Birgit	50:50	2021–2023
Maglaby	Kontu	50:50	2021–2023
Maglaby		100	2021–2023
Stäme	Birgit	50:50	2021–2023
Stäme	Birgit	75:25	2022–2023
Stäme	Kontu	50:50	2021–2023
Stäme	Kontu	75:25	2021–2023
Stäme		100	2021–2023
Ingrid	Birgit	50:50	2021–2023
Ingrid	Kontu	50:50	2021–2023
Ingrid		100	2021–2023
Ringeriksert	Birgit	50:50	2022–2023
Rustica	Birgit	50:50	2021–2023
Östgöta gulärt	Birgit	50:50	2022–2023
Concordia	Birgit	50:50	2022–2023

Data collection and analyses

Pod maturity was determined as days after sowing (DAS) when 95–100% of pods were fully mature. The canopy height close to harvest was measured from ground level to the top leaf (in the case of the semi-leafless pea Ingrid the tendril was used) of five randomly selected, but evenly distributed plants in each plot, avoiding the direct borders. The canopy height data was collected on the 15th of July in 2021 and 2nd of August in 2022 and 2023. Grain samples were harvested by hand from an area of 1 m^2 located as an intersect (0.5×2 m) across the plot. Grain harvest was conducted at two occasions depending on the maturity time of the varieties. The first harvest included treatments with the early maturing faba bean Kontu and pure stands of pea varieties Ingrid, Stäme, and Maglaby (Table 4). The second harvest included treatments with the later maturing faba bean varieties Birgit and Solberga, and pure stands of pea variety Solberga. In 2021, harvest dates were 22nd (97 DAS) and 26th of July (101 DAS); in 2022, 2nd (112 DAS) and 9th of August (119 DAS); and in 2023, 2nd (105 DAS) and 15th of August (118 DAS). The grains were threshed by hand and dried in a drying cabinet in 35 °C until constant weight, and stored in paper bags in room temperature until weighing (at 10–11% water content). Thousand grain weight (TGW) and seed area distribution was measured with a Marvin Seed Analyser (ProLine I, Marvitech, Germany). A subsample of 100–120 grains was measured from each sample. In cases where there were less than 100 grains in a sample, as many grains as possible were used. Each subsample was sifted with a 3.5 mm sift before analysis in order to clean out grain abortions and debris from threshing. The Marvin Seed Analyser measures seed area based on image analysis of photos taken from above of seeds laying on a flat surface.


faba bean
pea
2021
Ingrid a (a)
Stäme + B ab (d)
Maglaby + B a-c[2] (de[2])
Stäme a-d[2] (ab[2])
Stäme (75%) + K (25%) a-d[2] (ab[2])
Stäme + K a-d (cd)
Rustica + B a-d[1] (de[1])
Ingrid + B a-d (e)
Maglaby + K b-d (cd)
Birgit (B) c-d
Ingrid + K d (d)
Kontu (K) e
2022
Birgit (B) a
Concordia + B ab (c-g)
Stäme + B a-c (d-h)
Brattebräcka (25%) + B (75%) a-d (f-h)
Stäme (75%) + B (25%) a-d (a-c)
Rustica + B a-e (e-h)
Ingrid + B a-e (gh)
Ingrid a-e (a)
Ringeriksert + B a-e (e-h)
Stäme + K a-f (a-d)
Bjurholms småärt + B a-f (f-h)
Solberga (25%) + B (75%) a-f (c-g)
Stäme a-g (ab)
Ingrid + K b-g (b-g)
Brattebräcka + B b-g (b-f)
Solberga (faba) (S) b-g
Solberga + B b-h (b-e)
Maglaby + B c-h (d-g)
Maglaby + K d-h (c-g)
Bjurholms småärt (75%) + B (25%) e-h (c-g)
Stäme (75%) + K (25%) f-l (c-g)
Östgöta gulärt + B f-i (f-h)
Solberga + S g-j (e-h)
Kontu (K) h-j
Maglaby i-j (f-h)
Solberga j (h)
2023
Solberga (25%) + B (75%) a (ab)
Brattebräcka (25%) + B (75%) ab (b-e)
Birgit (B) a-c
Solberga + S a-d (ab)
Ingrid b-e (a)
Brattebräcka + B b-e (a-c)
Maglaby c-f (ab)
Rustica + B c-g (d-i)
Östgöta gulärt + B c-g (b-e)
Solberga + B c-g (b-d)
Bjurholms småärt (75%) + B (25%) c-g (b-f)
Ingrid + K d-h (c-g)
Ringeriksert + B d-i (h-j)
Ingrid + B d-i (d-i)
Solberga (faba) (S) d-j
Bjurholms småärt + B d-j (e-j)
Maglaby + K d-j (c-g)
Concordia + B e-j (ij)
Maglaby + B e-j (d-j)
Stäme + B f-j (f-j)
Solberga g-j (c-h)
Stäme + K h-k (g-j)
Kontu (K) i-k
Stäme (75%) + K (25%) jk (g-j)
Stäme (75%) + B (25%) jk (ij)
Stäme k (j)
Treatment
0 50 100 150 200 250 300 350 400 450 500 550
Grain yield (g m-2)

◂**Fig. 1** Total grain yield (g m^{-2}) of faba bean and pea intercropping and pure stands for 2021, 2022, and 2023 in separate panels (100 g m^{-2} is equivalent to 1 t ha^{-1}). Bars represent mean values of triplicate plots ± standard deviations for each species separately. Letters indicate significance groupings for each year separately, according to Fisher's Least Significant Difference (LSD), and are based on the total grain yield (of faba bean and pea together) and on the pea grain yield separately within parentheses. The variety name refers to the pea and the capital letter refers to the faba bean (B = Birgit; K = Kontu; S = Solberga). All intercropping treatments were sown in seed ratios 50% pea and 50% faba bean unless other percentages are indicated. Treatments marked with [1] come from one replicate and [2] from two replicates, due to pigeon damages. In 2021 treatments 'Maglaby', 'Solberga' and 'Solberga + B' are completely removed as all plots were damaged severely by pigeons

Statistical analyses

All statistical analyses were conducted with R 4.3.2 (R Core Team 2023). Effects of treatment and year were tested with analysis of variance (ANOVA) with block as random factor, in type II Wald F test and Kenward-Rogers degrees of freedom, and with $P < 0.05$ as the limit for statistically significant differences. Posthoc-test for significant differences of grain yield related analyses were conducted with Fisher's Least Significant Difference (LSD), and for DAS to pod maturation and TGW with Tukey's test.

Results

Grain yield

The total grain yields of all treatments and the individual yields of each component species is presented in Fig. 1. The grain yields were characterised by a high variation between the years, with 2022 generally producing much higher yields than 2021 and 2023 (pure stand faba bean yields were more than double in 2022 compared to the other years). Common for all years was that Birgit was the most productive faba bean variety, followed by Solberga and last Kontu. For the pea varieties, Ingrid was the most productive in pure stand, followed by Stäme, Maglaby and Solberga in descending order, with an exception for Stäme in 2023 (Fig. 1). Grain yield results for the pure stands of Solberga and Maglaby in 2021 were not included in the dataset due to severe pigeon damages. The differences between the pea varieties in pure stands were not always significant (Fig. 1). The modern pure stand control of pea was higher yielding than the modern pure stand control of faba bean in 2021, but opposite in 2022 and 2023.

Total grain yield

Both treatment, year and their interaction had significant effects on the total grain yield. The highest yielding treatment in 2021 was the pea variety Ingrid in pure stand, but it did not differ significantly from the majority of the intercrop treatments (Fig. 1). In 2021, the faba bean variety Birgit in pure stand yielded less than Ingrid and higher than the pure stand of the faba bean variety Kontu, but did not differ significantly from any of the other treatments that year. In 2022, Birgit in pure stand had the highest total yield of all treatments, but was only significantly higher than the 13 lowest producing treatments that year (*i.e.* all the treatments that were less productive than Stäme in pure stand, Fig. 1). There was no significant difference between pure stands of Birgit and Ingrid, but the yield of Ingrid was only significantly higher than a few of the lowest producing treatments (Fig. 1). In contrast, the highest total yields in 2023 were obtained with intercropping treatments of the pea varieties Brattebräcka and Solberga grown with Birgit in 25:75 ratio. Among these two treatments, the highest yielding (Solberga pea with Birgit in 25:75) was significantly higher than pure stand of Ingrid, but not Birgit. Just like in 2022, Ingrid in pure stand was only more productive than a few of the lowest producing intercropping treatments in 2023, while Birgit in pure stand yielded higher than a bit more than half of the intercropping treatments (Fig. 1).

Alternating seeding ratios of pea and faba bean did not affect the total grain yield much. The only case where a significant difference was found between seeding ratios was in 2023 when Solberga grown with Birgit in 25:75 ratio (pea:faba bean) produced a higher total yield than its 50:50 counterpart. In addition, intercropping with Birgit tended to contribute to a higher total yield compared to intercropping treatments with Kontu and Solberga (faba bean), but never to a degree that was statistically significant (this was also the case when the intercropping treatments were analysed without pure stand treatments). Altogether, the largest variations in total grain yields were seen between years and between variety combinations, but not much between seeding ratios.

Pea grain yield

Both treatment, year and their interaction had significant effects on the pea grain yield when analysed separately from that of faba bean. The modern control Ingrid in pure stand always had the highest yield when comparing all pea yields irrespectively of treatment (*i.e.* including both pure stands and all types of intercropping treatments). These were however not significantly different from the yields of several traditional pea varieties when cultivated with a faba bean (Fig. 1). Intercropping treatments with pea yields similar to those of Ingrid in pure stand were Stäme grown with Birgit in 75:25 ratio (pea:faba bean) or Kontu in 50:50 ratio in 2022. In 2023 similar yields were obtained with Solberga intercropped with either Birgit in 25:75 ratio or Solberga (faba bean), as well as Brattebräcka with Birgit in 50:50 ratio. Similar yields to Ingrid in pure stand were also produced by pure stands of Stäme in 2021 and 2022, and Maglaby in 2023. Intercropping pea with Kontu instead of Birgit sometimes resulted in a higher pea yield. There were occasions where alternated seeding ratios changed the yield outcome of the pea, but these effects were not consistent over the years.

To compare how pea varieties performed under the same intercropping conditions, all pea yields from treatments that were intercropped with faba bean variety Birgit in 50:50 seeding ratio were analysed together (*i.e.* all other treatments were excluded from the analysis). In 2021, this involved pea varieties Ingrid, Stäme, Maglaby and Rustica, and in 2022 and 2023 all ten pea varieties of the experiment (Table 3). The only significant yield differences were: in 2021, Stäme was more productive than the lowest yielding variety Ingrid; in 2022, Solberga and Brattebräcka had significantly higher yields than Bjurholms småärt, Östgöta gulärt and Ingrid; and in 2023 Brattebräcka had significantly higher yields than all but the two second highest yielding varieties Solberga and Östgöta gulärt. In addition, in 2023, Solberga and Östgöta gulärt had significantly higher yields than about half of the lower yielding treatments (Maglaby, Bjurholms småärt, Stäme, Ringeriksert, and Concordia).

Impact of different pea varieties and seeding ratios on the faba bean yield

The competitive impact of the different pea varieties on the faba bean yield in intercropping treatments was assessed with the faba bean Birgit in 50:50 ratio on a yearly basis (Fig. 2). The pea varieties with very long and vining plants, Solberga and Brattebräcka, expressed a high level of competition on the faba bean which produced very low yields in these intercropping treatments. This was also the case for Östgöta gulärt, which is slightly shorter, but nevertheless a long and vining variety. The short pea varieties Stäme and Concordia, and the slightly longer semi-leafless variety Ingrid, tended to allow for a higher faba bean yield, which was also the case for the long and vining varieties Rustica and Ringeriksert. The significant differences between treatments were not consistent over the years (Fig. 2).

The impact of seeding ratio on the faba bean yield (Fig. 1) was analysed with all intercropping treatments with Birgit. Increasing the proportion of pea in the intercropping mixture generally reduced the faba bean yield. This effect was the case for Stäme and Bjurholms småärt with Birgit in 75:25 ratio (pea:faba bean) compared to 50:50 ratio and Brattebräcka and Solberga with Birgit in 50:50 ratio compared to 25:75 ratio. For the latter two, the gain in faba bean yield when grown in 25:75 ratio tended to be higher than the reduction of pea yield, generally making the 25:75 ratio more productive (however only significant for Solberga in 2023).

Seed size

Thousand grain weight

Both species included varieties with a wide range of TGW values (Table 5). Most pea varieties had TGW values that were lower than the faba bean. The pea varieties with the largest seeds did however have overlapping or higher TGW than the faba bean varieties Birgit and Kontu (Table 5). Solberga was the only faba bean variety that had higher TGW than all pea varieties. Differences in TGW was analysed separately for each faba bean variety, and for the pea varieties that were also included in pure stands: Ingrid, Maglaby, Stäme, and Solberga. Analyses were conducted over three years for treatments that were included in 2021–2023, and over two years for the

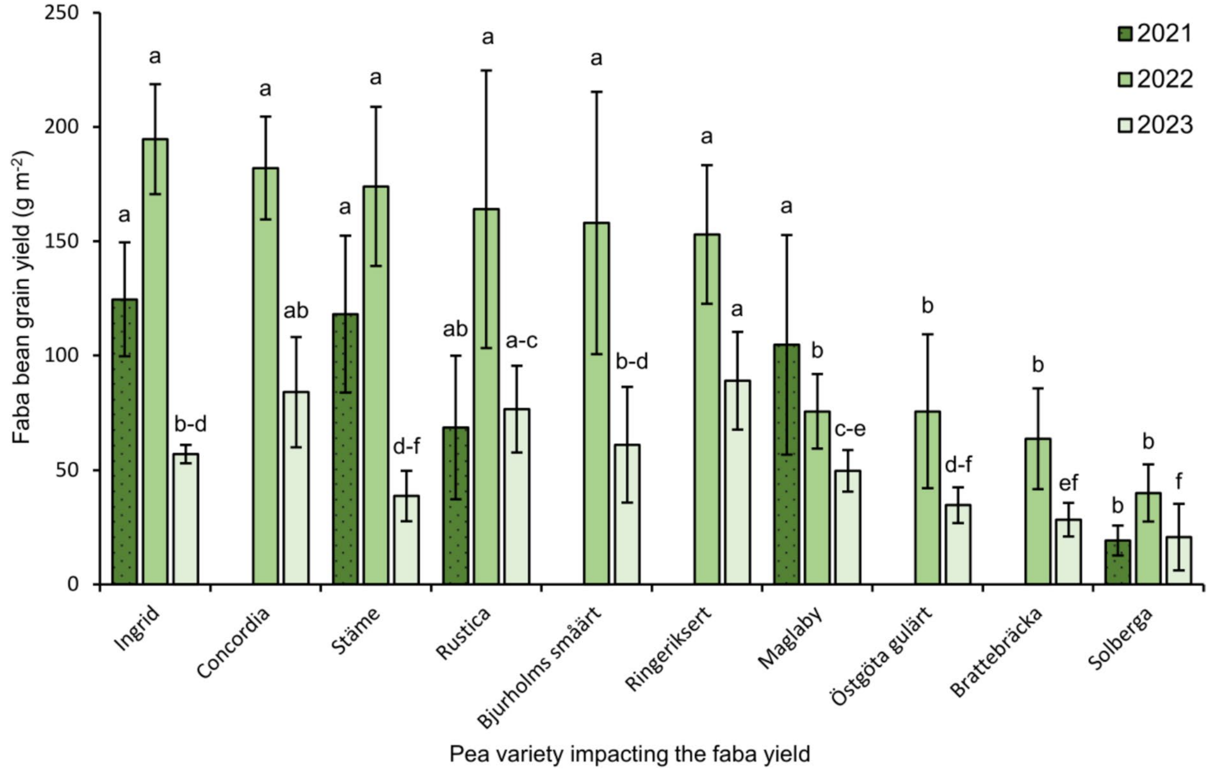


Fig. 2 Grain yield (g m^{-2}) of the faba variety Birgit when intercropped with different pea varieties in seeding ratios of 50:50 during 2021 to 2023 (100 g m^{-2} is equivalent to 1 t $ha.^{-1}$). Letters indicate significance groupings for each year separately, according to Fisher's Least Significant Difference (LSD). Treatments with only two columns were only included in 2022–23

treatments included in 2022–2023. Unlike the other assessed traits in this study, the TGW did not show an interaction between year and treatments, with an exception for the pea variety Solberga. Intercropping did generally not have an impact on TGW, and the few exceptions where intercropping did change the TGW were not consistent across years or between varieties (*i.e.* a certain companion variety and seeding ratio did not have the same impact on the different varieties).

Seed area distribution

The results of the distribution of seed areas in Fig. 3 presents average values from all treatments and years of each variety, and aims to give a general overview of the variation of seed sizes within a variety, rather than comparing treatment effect (which was conducted for the TGW). The set of varieties used in this experiment included a wide range of seed sizes among both species—generating both overlaps and differences in seed size between the two species depending on variety choice (Fig. 3).

Time to pod maturity

The time from sowing to pod maturity of both species was affected by both treatment (variety) and year and the interaction of the two, irrespectively if analysed over two or three years, but intercropping did not have any effect (Table 6). In most cases, there was a difference in maturity time between the two species within the intercrop treatments, however, even maturity was achieved when combining the faba bean variety Birgit with pea varieties Brattebräcka and Solberga, as well as faba bean Kontu with pea variety Maglaby. In addition, several pea varieties that were only tested with Birgit had similar maturity time as Kontu. The faba bean variety Solberga had similar maturity time

Table 5 Thousand grain weight (TGW) of all treatments 2021–2023 (measured at 10–11% water content). Results shown are mean values in grams and standard deviations (in brackets). For the intercropping treatments the names to the left are pea and abbreviations are faba bean varieties (B = Birgit; K = Kontu; S = Solberga). All intercropping treatments were sown in seed ratio 50% pea and 50% faba bean unless other percentages are indicated

	Pea			Faba bean		
Treatment	2021	2022	2023	2021	2022	2023
Birgit (B)				359 (60)	454 (13)	471 (18)
Kontu (K)				207 (45)	259 (8)	246 (14)
Solberga (faba) (S)					819 (43)	691 (91)
Brattebräcka + B		219 (3)	246 (12)		407 (23)	473 (23)
Brattebräcka (25%) + B (75%)		226 (13)	241 (7)		425 (29)	475 (31)
Bjurholms småärt + B		125 (6)	137 (27)		433 (26)	457 (14)
Bjurholms småärt (75%) + B (25%)		122 (1)	119 (4)		390 (26)	484 (17)
Concordia + B		220 (3)	207 (9)		447 (10)	444 (31)
Ingrid	244 (7)	248 (13)	223 (7)			
Ingrid + B	228 (13)	247 (1)	208 (3)	391 (30)	435 (49)	437 (29)
Ingrid + K	260 (18)	244 (9)	217 (11)	212 (8)	244 (21)	220 (12)
Maglaby	92 (5)	102 (4)	118 (4)			
Maglaby + B	101 (18)	120 (5)	126 (8)	402 (30)	420 (22)	468 (25)
Maglaby + K	103 (6)	115 (11)	129 (4)	209 (19)	246 (12)	223 (28)
Rustica + B	194 (8)	185 (10)	185 (7)	392 (14)	421 (41)	523 (18)
Ringeriksert + B		111 (6)	118 (6)		436 (21)	441 (100)
Stäme	317 (7)	265 (7)	268 (22)			
Stäme + B	319 (24)	295 (8)	253 (14)	408 (22)	436 (12)	440 (37)
Stäme + K	315 (32)	283 (9)	277 (14)	197 (20)	243 (30)	210 (20)
Stäme (75%) + B (25%)		282 (16)	262 (34)		429 (12)	433 (33)
Stäme (75%) + K (25%)	321 (30)	267 (4)	282 (16)	208 (53)	217 (3)	219 (12)
Solberga	411 (40)	437 (26)	493 (3)			
Solberga + B	455 (10)	491 (5)	459 (30)	390 (22)	378 (21)	456 (108)
Solberga + S		458 (22)	496 (26)		612 (53)	658 (197)
Solberga (25%) + B (75%)		501 (9)	526 (21)		430 (23)	481 (31)
Östgöta gulärt + B		156 (13)	138 (8)		402 (7)	414 (29)

as the pea variety Solberga in 2022, while it differed in 2023.

Canopy height at harvest

Canopy height ranged from as low as 4 cm up to 139 cm among all collected data points (Fig. 4). In general, the highest canopies were observed for pure stands of faba bean varieties Birgit and Solberga in 2022, and the lowest for pure stands of pea varieties Stäme in 2022 and Maglaby in 2023. In all cases where comparison can be made for pea in pure stands versus intercropping, there was a gain in canopy height from the intercropping treatment, with an exception of the modern semi-leafless variety Ingrid (which also had good standing ability when cultivated in pure stand). None of the traditional pea varieties were resistant to severe lodging when grown without a companion crop. In cases where the supportive capacity of faba bean could be compared between the varieties Birgit and Kontu, the former contributed to a higher canopy height (with exception of Ingrid in all years and Stäme in 2023). Solberga (faba bean) had a similar supportive capacity as Birgit when intercropped with Solberga (pea). A higher seeding ratio of faba bean also contributed to a higher canopy height of the pea. Many treatments exhibited an unevenness in their canopy height (Fig. 4). In addition, many intercropping treatments contributed to a reduced canopy height of the faba bean, as compared to when grown in pure stand. In 2022 such decrease in faba bean height was evident and can be observed when intercropped with long (and very long) and vining pea varieties, as well as short and erect ones when grown in 75:25 seeding ratio (pea:faba bean). In 2021 this was also the case, but with Rustica grown with Birgit as an exception in which no height reduction was observed. In 2023 such effects was less apparent as growth was generally reduced for all treatments.

Discussion

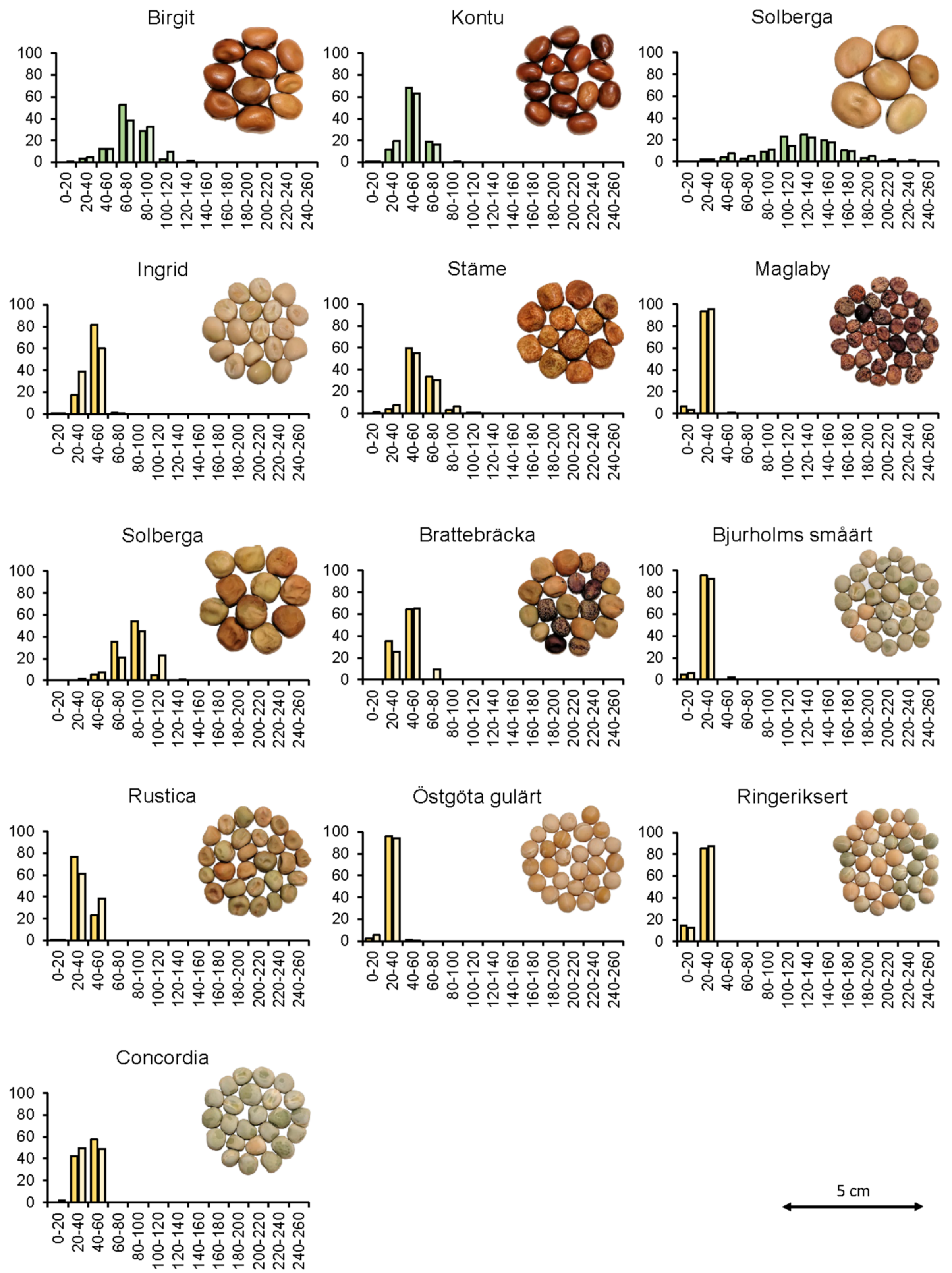
Intercropping traditional pea varieties for organic grain production

This study evaluated faba bean and pea intercropping with regard to producing high grain yield in organic farming systems, and to utilise this species combination as a means to facilitate production of traditional pea varieties. Such pea varieties, in contrast to modern semi-leafless varieties, require standing support for production on an arable scale with standard machinery for grain harvest. The results show that faba bean and pea intercropping can generate total yields (*i.e.* sum of grain yields for both species) similar to pure stands of modern controls (*i.e.* varieties commonly used in contemporary local organic farming). These results support findings in previous studies on the potential for faba bean-pea intercropping (Stelling 1997; Živanov et al. 2018). However, those previous studies were restricted to modern varieties, while this study obtained similar and sometimes even higher total yields by intercropping traditional pea varieties as well (Fig. 1; Table 4).

There is a lack of registered varieties suitable for the diverse needs of organic agriculture and the different farming methods (*e.g.* intercropping) that may be used to improve it (Desclaux and Nolot 2014). This study shows that locally adapted traditional varieties can be good candidates for organic grain yield production if intercropped. In addition, traditional pea varieties may stimulate the interest for organic produce through their diversity of culinary and cultural attributes (Westling et al. 2024; Chable et al. 2020), and reverse some of the agrobiodiversity loss that has occurred during the last century (Ceccarelli et al. 2012; Lara and Ryan 2025). The promising results in this study, with regard to grain yields of traditional pea varieties when intercropped with faba bean, motivates further studies to explore their potential for cultivation at a larger scale, as well as to better understand the underlying crop traits and ecosystem services relevant for organic farming and other agroecological production systems.

In 2023, the two highest yields were generated by the two pea landraces Solberga and Brattebräcka grown with Birgit in 25:75 ratio (pea:faba bean) (Fig. 1). This year was characterised by early summer drought and the results therefore indicate a potential drought tolerance of these pea varieties. They both originate in the same region in Sweden and share similar plant lengths and growth habits (*i.e.* vining and 2–3 m long). Solberga was traditionally intercropped with faba bean and was known to be climate resilient (personal communication with Lars Eliasson; the donor of the seeds and whose family has cultivated it for many generations). In contrast, the traditional pea varieties Concordia and Stäme seemed to express high drought sensitivity, indicated by a more pronounced yield reduction between 2022 and 2023 compared to the control variety Ingrid (Fig. 1). These varieties have short stems and early maturation, and a higher share of its growth time coincided with the drought period. This was also the case for Ringeriksert, although it has a different above ground plant architecture with a longer stem and vining growth habit.

Another interesting observation related to the Solberga pea was its capacity to generate higher pea yield when being intercropped. The most evident example was in 2022 when Solberga grown with Birgit in 50:50 and 25:75 (*i.e.* the pea being sown in 50% and 25% of its pure stand seeding rates) generated approximately 1.9 and 1.6 (respectively) times higher pea yield than its pure stand. This indicates a high adaptation of the pea variety Solberga to intercropping systems. Intercropping of this pea variety did in other words contribute to much higher pea grain yield, even if the seeding rate was much lower compared to its pure stand counterpart. In contrast, the modern pea control Ingrid (that was the most productive pea in pure stand) was the lowest yielding pea variety in two out of three years when comparing all pea varieties in 50:50 intercropping with Birgit, indicating the


Birgit
Kontu
Solberga
Ingrid
Stäme
Maglaby
Solberga
Brattebräcka
Bjurholms småärt
Rustica
Östgöta gulärt
Ringeriksert
Concordia
0
20
40
60
80
100
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
200-220
220-240
240-260
5 cm

◂**Fig. 3** Seed area distribution chart of all varieties included in the experiment. The y-axis shows percentage (%) of seeds and x-axis shows area intervals (mm^2). Percentages are mean values of all treatments that were included for each variety (intercropping and pure stands). Green columns (top row) are faba bean varieties while yellow columns are pea varieties. Darker columns (positions to the left) represent data from 2022 and lighter columns (positioned to the right) represent data from 2023. All seeds in the pictures are in proportionate size to each other, with a 5 cm scale bar indicated with the double-ended arrow

adaptation of traditional pea varieties to intercropping over pure stands, or potentially the maladaptation of the modern variety to intercropping conditions. These findings suggest that intercropping studies only using modern pea varieties (developed for cropping in pure stand) might undervalue the potential of intercropping for pea grain production. Besides showing the potential of direct use of traditional varieties in organic intercropping systems, this study may also contribute to the emerging field of plant breeding for intercropping (Annicchiarico et al. 2019; Bourke et al. 2021; Haug et al. 2021). Not only does this study show the different effects of a wide range of plant architectures in an intercropping system, it also highlights seeding ratio as an important factor in the target environment for intercrop breeding.

Competitive impact of different pea varieties on the faba bean

Faba bean grain yields of Birgit intercropped with different pea varieties varied over the years and the differences between treatments were inconsistent. There are, however, some general observations. The very long (2–3 m) and vining pea varieties, Brattebräcka and Solberga, imposed a strong competition on the faba bean, reducing its yield levels significantly compared to the pea varieties with short and medium stem lengths, however, they also differentiated from some of the long and vining ones (*i.e.* Rustica and Ringeriksert; Fig. 2). On the contrary, the short traditional pea varieties, Stäme and Concordia, and the modern semi-leafless variety Ingrid, tended to allow for a high faba bean yield. The long and vining pea varieties, Rustica, Ringeriksert, Maglaby, Östgöta gulärt, and Bjurholms småärt (slightly shorter), ranged in competition ability towards faba bean, indicating that there are more factors influencing the faba bean yield than plant length and growth habit of the pea.

Seed traits and potential of post-harvest separation

Thousand grain weight was assessed in relation to the intercropping treatments, which is of high relevance for post-harvest separation of seeds from the two crops. Both faba bean and pea TGW is to a high extent determined genetically (Ohm et al. 2024; Georgieva et al. 2016). Even though the varietal differences in TGW were large for both species, the TGW generally did not change due to intercropping, indicating that the yield parameter influenced by the different treatments was the number of seeds, a finding that is in line with the results of Živanov et al. (2018). The few observed exceptions when TGW was influenced by the intercropping treatment did not follow a trend strong enough to draw any conclusions from.

The relevance of seed size (as well as shape and colour depending on separation method) depends on the end use and whether or not grains of the two species need to be separated after harvest. Seed area distribution was included as a complement to the TGW as a basic indicator of the possibility to separate the two species after harvest. As TGW is a mean value, it alone may be misleading in the sense that differentiated TGW values might give a false sense of differentiation in seed size, while in reality there might be an overlapping size distribution between the seeds of the two species.

This study shows that the utilisation of traditional varieties may contribute to a higher likelihood of finding varieties that can be separated after harvest. The traditional pea varieties, Bjurholms småärt, Maglaby, Ringeriksert and Östgöta gulärt, had smaller seeds than the modern control Ingrid and were distinguished from the seed size of faba bean varieties Birgit and Solberga. The traditional faba bean variety Solberga also had bigger seeds than modern faba bean varieties Birgit and Kontu, making it distinguished from the seed size of more pea varieties compared to the other faba beans (Fig. 3). Kontu had the smallest seeds of all the faba bean varieties, and a seed area distribution that was overlapping with all pea varieties, probably making size-based separation difficult. Similarly, the pea varieties with seeds mainly ranging within the 20–60 mm^2 interval

Table 6 Maturity time (days after sowing; DAS) of all treatments 2021–2023. Results shown are mean values and standard deviations (in brackets). For the intercropping treatments the names to the left are pea and abbreviations are faba bean varieties (B = Birgit; K = Kontu; S = Solberga). All intercropping treatments were sown in seed ratios 50% pea and 50% faba bean unless other percentages are indicated

	2021		2022		2023	
Treatment	Pea	Faba bean	Pea	Faba bean	Pea	Faba bean
Birgit (B)		104 (0.0)		116 (1.2)		111 (3.5)
Kontu (K)		94 (0.0)		106 (0.0)		94 (0.0)
Solberga (faba) (S)				119 (0.6)		107 (0.0)
Brattebräcka + B			112 (6.1)	115 (0.6)	116 (2.9)	110 (5.8)
Brattebräcka (25%) + B (75%)			116 (1.2)	116 (1.0)	117 (3.2)	113 (0.0)
Bjurholms småärt + B			105 (1.0)	115 (0.0)	100 (4.6)	113 (0.0)
Bjurholms småärt (75%) + B (25%)			105 (0.6)	115 (0.0)	101 (2.1)	111 (3.5)
Concordia + B			104 (1.2)	117 (0.0)	95 (1.2)	110 (2.3)
Ingrid (100%)	94 (0.0)		97 (0.0)		90 (0.0)	
Ingrid + B	94 (0.0)	104 (0.0)	97 (0.0)	117 (0.6)	90 (0.0)	113 (0.0)
Ingrid + K	94 (0.0)	94 (0.0)	97 (0.0)	105 (0.6)	90 (0.0)	96 (0.0)
Maglaby (100%)	95 (0.6)		104 (0.6)		98 (2.1)	
Maglaby + B	96 (0.6)	104 (0.0)	104 (1.5)	115 (0.0)	98 (2.1)	111 (3.5)
Maglaby + K	96 (0.6)	94 (0.0)	105 (2.0)	105 (0.0)	99 (1.2)	96 (0.0)
Rustica + B	99 (0.0)	104 (0.0)	102 (3.5)	116 (1.2)	95 (1.2)	113 (0.0)
Ringeriksert + B			104 (0.6)	116 (1.2)	103 (4.7)	115 (2.9)
Stäme (100%)	94 (0.0)		97 (0.0)		87 (0.0)	
Stäme + B	94 (0.0)	104 (0.0)	97 (0.0)	115 (0.0)	87 (0.0)	113 (0.0)
Stäme + K	94 (0.0)	94 (0.0)	97 (0.0)	105 (0.0)	87 (0.0)	96 (0.0)
Stäme (75%) + B (25%)	94 (0.0)	94 (0.0)	97 (0.0)	116 (1.2)	87 (0.0)	113 (0.0)
Stäme (75%) + K (25%)	94 (0.0)	94 (0.0)	97 (0.0)	105 (0.0)	87 (0.0)	96 (0.0)
Solberga (100%)	113 (0.0)		120 (0.0)		113 (0.0)	
Solberga + B	113 (0.0)	104 (0.0)	119 (0.6)	116 (2.3)	115 (2.9)	111 (3.5)
Solberga + S			119 (1.2)	116 (1.2)	115 (3.5)	103 (0.0)
Solberga (25%) + B (75%)			118 (1.0)	117 (2.1)	115 (2.9)	112 (2.3)
Östgöta gulärt + B			106 (1.7)	115 (0.0)	98 (0.6)	112 (2.3)

(Brattebräcka, Concordia, Ingrid, and Rustica) had a slight overlap with faba bean variety Birgit.

Some pea varieties also have round seeds (Östgöta gulärt, Ringeriksert, and Bjurholms småärt) which tend to roll easier than pea varieties with wrinkled and/or other seed shapes. There are also differences between the faba beans in seed shape, with Solberga tending to be more flat compared to relatively more globular (but not round) varieties Birgit and Kontu. Selecting varieties with differences in such traits might further increase the potential of successful separation. Further studies including practical assessments are needed to fully comprehend the requirements of machinery to efficiently separate faba bean and pea seeds from each other. Such studies should preferably also consider the potential of different seed shapes and colours as traditional pea and faba bean varieties express large diversity in these traits (Fig. 3), that might be useful for colour based post-harvest separation (including optical sorting).

Maturity times

Matching maturity times of the two companion species is of great importance for grain production. If seed maturation do not match, there is a risk of getting reduced yields due to seed shattering or field sprouting of the earliest maturing species before the harvest can be done. There are no other studies assessing such a wide range of varieties of pea and faba bean with regard to their matching maturity times. In this study, there were both matching and non-matching alternatives among the varieties of the two companion species (Table 6). The compatibility can be attributed to the diversity of traditional pea varieties and the inclusion of the Finnish faba bean variety Kontu, developed for its earliness traits (Stoddard and Hämäläinen 2011). It can be noted that if only the locally used modern varieties Ingrid (pea) and Birgit (faba bean) would have been included in the experiment, matching maturity times would not have been found.

Interestingly, matching maturity times between pea and the faba bean variety Birgit, which has a typical maturity time for a modern faba bean variety grown in southern Sweden (Hagman and Halling 2020), were observed for the two pea landraces Solberga and Brattebräcka. These landraces originate in a region in Sweden that has a known history of faba bean and pea intercropping (Leino et al. 2023). Matching maturity times was also observed for the combination of the pea variety Maglaby together with the faba bean variety Kontu. Other pea varieties such as Bjurholms småärt, Concordia, Rustica, Ringeriksert, and Östgöta gulärt shared similar maturity times with Maglaby and Kontu, but were only tested in intercropping with Birgit.

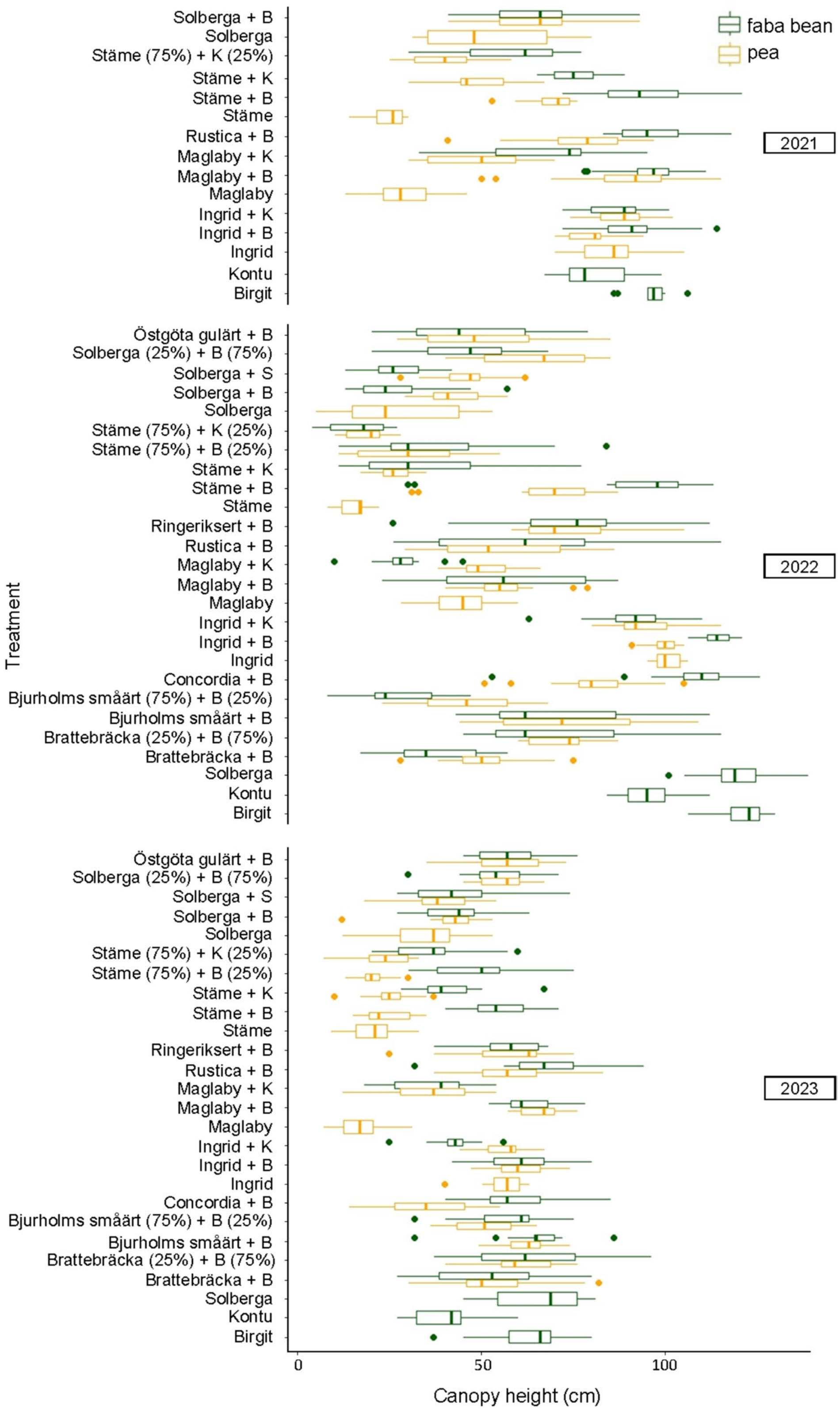
The maturity time of faba bean and pea varieties in this study was measured as the time in days between sowing and pod maturation. However, in an actual farming situation this time interval may be longer, since the stem maturation (when the stem is dry) is also an important criterion for farmers deciding when to harvest (Holstmark 2022a). Another factor also relevant for intercropping of pea and faba bean for the production of mature grains, is the resistance to pod shattering and capacity to maintain seed quality if harvest is delayed due to unevenness in maturation time. Pod shattering was not systematically assessed in this study, but was not observed as a common phenomenon. Resistance to pod shattering and seed quality loss could be equally important as maturity time when considering traits in breeding for this type of intercropping.

Canopy height close to harvest time

The risk of severe lodging is one of the main concerns when cultivating traditional pea varieties. Lodging makes mechanical harvest difficult, increases the risk of pathogen infections and soil/gravel contamination of harvested seeds, and make the crop more susceptible to bird damages—as observed in the first year of this experiment (causing the use of anti-bird nets in the subsequent years). This study was not designed to go in-depth on mechanisms contributing to lodging resistance, but revealed differences in standing ability among pea varieties and between pure stands and intercrops. In contrast to the modern semi-leafless pea variety Ingrid, the traditional pea varieties grown in pure stand lacked proper standing ability on their own. Many of the traditional pea varieties have a vining growth habit, which further increase the need of a supportive crop for them to be produced on arable scale, but even the variety Stäme, which has an erect growth habit, showed high susceptibility to lodging when grown in pure stand. The results show that intercropping traditional pea varieties with faba bean can improve their standing ability to an acceptable degree (*i.e.* making it possible to harvest and avoid severe lodging). However, depending on their plant length and growth habit, seeding ratios and choice of faba bean variety should be optimised for good results. In general, the larger plants the traditional pea varieties have the more support they need. This can be gained by using faba bean varieties with stronger plants as well as increasing the ratio of faba bean to pea in the mixture (*i.e.* it was observed that higher proportions of faba bean variety Kontu was needed to obtain similar support as Birgit in the crop mixtures). It is also evident that results from the modern pea control Ingrid cannot be translated to traditional pea varieties, which emphasises the need of alternative production guidelines for traditional pea varieties and their subtypes.

Conclusion

Intercropping pea with faba bean can enable arable farming of traditional pea varieties that are subject to severe lodging when grown in pure stand. This type of intercropping often showed to be as productive as modern varieties of either species in pure stand. The


faba bean
pea
2021
2022
2023
Solberga + B
Solberga
Stäme (75%) + K (25%)
Stäme + K
Stäme + B
Stäme
Rustica + B
Maglaby + K
Maglaby + B
Maglaby
Ingrid + K
Ingrid + B
Ingrid
Kontu
Birgit
Östgöta gulärt + B
Solberga (25%) + B (75%)
Solberga + S
Solberga + B
Solberga
Stäme (75%) + K (25%)
Stäme (75%) + B (25%)
Stäme + K
Stäme + B
Stäme
Ringeriksert + B
Rustica + B
Maglaby + K
Maglaby + B
Maglaby
Ingrid + K
Ingrid + B
Ingrid
Concordia + B
Bjurholms småärt (75%) + B (25%)
Bjurholms småärt + B
Brattebräcka (25%) + B (75%)
Brattebräcka + B
Solberga
Kontu
Birgit
Treatment
0
50
100
Canopy height (cm)

◂**Fig. 4** Canopy height (cm) close to harvest time (0–13 days before harvest). Each boxplots represents 15 measurements (5 measurements per plot × 3 replicate blocks). Each segment of the boxplot includes 25% of the values. Outlier values are shown as dots. The variety name refers to the pea and the capital letter refers to the faba bean (B = Birgit; K = Kontu; S = Solberga). All intercropping treatments are sown in seed ratios 50% pea and 50% faba bean unless other percentages are indicated

great phenotypic diversity among traditional pea varieties contributed to the identification of variety combinations with similar maturity time and segregation in seed size (relevant for post-harvest separation), but makes it difficult to propose one standard intercrop-design that works for all varieties. Instead, this study has identified some relevant design-parameters, and highlights the need of different intercrop-designs for different varieties.

The choice of pea variety, different priority in yield outcome (*i.e.* maximised pea yield vs. maximised total yield of both species), and potential requirement of post-harvest separation of the grains, require matching faba bean variety and seeding ratio. Avoiding severe lodging by having a sufficient density and stem strength of faba bean plants in the mixture is crucial, and different faba bean varieties contribute different amount of support to the pea plants. The seeding ratio (*i.e.* proportions of faba bean and pea) should however be balanced to minimise interspecies competition—for prioritised pea grain production, the tipping point (literally) is when the pea yield is as high as possible without risking severe lodging, while for prioritised total grain production the proportion of faba bean can be increased to provide additional standing support. Traditional pea varieties with larger plant phenotypes generally require higher proportions of faba bean, while those with smaller plant phenotypes require less.

Although growing traditional pea varieties with faba bean shows promise as an alternative for grain legume production in organic agriculture, it may still be a challenge to find varieties with the right combination of stem strength, maturity time and seed size—especially if post-harvest separation of the grains is required. Therefore, more studies are recommended to optimise and fully understand this intercrop-combination, *e.g.* replacement or additive design and differentiated sowing times of the component species. Finding locally adapted varieties with overlapping harvest times is a recommended first step for evaluating this farming method in other localities.

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Data availability All data is provided within the manuscript.

Declarations

Competing interests The authors declare no competing interests.

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