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Breeding of a protein pea ideotype for Finnish conditions

Abstract. The characteristics of protein pea (*Pisum sativum* L.) adapted to cultivation in Finnish conditions were specified. Ideotypes for pure and mixed stands were defined separately. Factors affecting seed yield, protein yield and protein content were determined. Efficiency of biological nitrogen fixation in the varieties was evaluated at two nitrogen application levels, 16 and 80 kg/ha. Selection methods for increasing protein content were discussed. The commercial varieties bred during the programme were presented. The effect of the gene *af* on different characteristics of the pea was the central object of the studies.

The ideotype of peas for cultivation in Finland has to be of the afila-type. This concerns cultivation in both pure and mixed stands. Afila-peas gave seed yields and protein yields as high as the leafed ones. The lodging of afila-peas throughout the generative growth phase was less than that of the conventional leaf types. In mixed cropping the most suitable afila-peas generally formed almost completely unlodged stands together with cereals. The best seed yields were given by the varieties with a stem height of 61 to 94 cm. Due to competition, the corresponding height in mixed stands ranged from 80 to 100 cm. For the same reason, varieties to be used in mixed stands must possess a fairly large seed size and fast growth rate after emergence.

The optimum flowering period lasted from 19 to 28 days. The varieties must be early, with a growing time from 91 to 101 days. Late varieties are not adapted to northern conditions, giving low yields and poor quality.

The mean yield of the varieties was 4500 kg/ha in pure stands. The high nitrogen application level of 80 kg/ha did not increase pea yield in comparison with the 16 kg/ha level. In contrast, it enhanced the protein content by 1 % and the protein yield slightly. In mixed stands the mean total yield was 4700 kg/ha. The hectare yields of crude protein reached levels of 990 and 900 kg respectively. Early varieties tend to have a low protein content. The protein content ranged from 15.4 to 27.6 per cent in the unselected line material. A negative, although weak correlation was found between seed yield and protein content. A variety with the highest protein yield must exceed the average level both in seed yield and protein content. The varieties with the highest protein yields had a content of 23—27 per cent.

Index words: pea, pea breeding, pea ideotype, afila-peas, protein pea, semi-leaflessness, pea varieties, harvest index, lodging

Introduction — the afila character in breeding

Five important factors have initiated the need to emphasize pea (*Pisum sativum* L.) breeding:

1. In spite of considerable efforts, little progress has been made in cereal breeding for higher protein content and protein quality. Therefore, more emphasis is being put on breeding directed at biologically more efficient protein producers (KIVI 1979, AIKASALO and KESÄLÄ 1985).

2. The breeding prospects of peas are good as a result of the broad variability expressed by the crop (BLIXT 1972, 1978 b). Very much is known about the character differences that are controlled by monogenic effects with distinct and extreme phenotypic consequences. At present, the number of monogenic characters in pea exceeds 500 (MARX 1985).

3. The pea belongs to the few field crops whose biological nitrogen fixation can be exploited as north as in Finland (VIRTANEN 1935, HÄNNINEN 1956). The conventional pea varieties do not need any nitrogen application, thus saving the costs of mineral fertilizers (SUNDMAN and VARIS 1983).

4. The possibilities for extensive protein production through the cultivation of peas have been verified by many yield experiments (HOVINEN 1980, 1983 b, HOVINEN and VARIS 1983).

5. Breeding of new, essentially improved varieties with good adaptability has been accepted as the most important prerequisite for extensive protein pea production (ANON. 1984, KIVI 1984).

The poor lodging resistance has been the major hindrance against high adaptability of peas to Finnish conditions. Since incorporation of an afila-pea variety Usatij 5 into the crossbreeding programme at Hankkija Plant Breeding Institute in 1970, the potentiality of the afila-character in improving standing ability was by and large realized.

The mutant gene *af* of pea results in the formation of tendrils instead of leaflets (SNOAD 1974). KUJALA (1953) first described the afila-character or leaflessness, and suggested the gene symbol *af*. The gene *af* can be an induced mutation (SNOAD 1974, KIELPINSKI and BLIXT 1982), or can be found in the progeny from a cross between genetically distant varieties (MAKASHEVA 1983). The gene *af* is a typical single gene with clearcut morphogenetic effects (YOUNG et al. 1983). SWIECICKI (1982) demonstrated through genetic analysis that afila phenotypes from different sources were determined by the same *af* or *afila*-gene. The gene is located on chromosome 1, (BLIXT and GOTTSCHALK 1975, KIELPINSKI 1982).

The mutant gene *st* causes stipules to grow in the form of narrow strips. The genotype *afaf. stst* so-called Filby-type is totally leafless in phenotype (SNOAD 1974, 1985). The gene *st* is located on chromosome 3 (LAMPRECHT 1961). The genotype *afaf. stst* was originally called "leafless", and the genotype *afaf. StSt* "semileafless" (HEATH and HEBBLETHWAITE 1984). The sharply defined term for the latter is "afila-pea" (KIELPINSKI and BLIXT 1982).

Compared with leaves, tendrils are inferior photosynthetic organs because they have evolved to support the plant. Replacement of leaflets by tendrils diminishes the leaf area index (LAI). In measurements made by PYKE and HEDLEY (1985) fifty days from sowing, the genotype *AfAf* had an LAI value of 5.1, *afaf* 3.5, and *afaf. stst* only 1.1. The stem growth of the genotype *afaf. StSt* in the seedling stage, as well as the growth rate of the seedlings, are the same as for the genotype *AfAf. StSt*. On the other hand, the genotype *afaf. stst* grows soo slowly during the seedling stage. Photosynthesis by the stipules is important for the growth of seedlings and stem (Hedley and Ambrose 1981, Pyke and Hedley 1982 b). The genotype *afaf* has a more evenly distributed leaf area and the lower part of the stand receives more light compared to the genotype *AfAf* (Snoad 1974, Bingefors et al. 1979 a, Cousin et al. 1985). Hobbs and Mahon (1985) found that the photosynthetic efficiency per green area unit of plant organs of leafless peas could be increased, thus increasing phytomass production. Photosynthesis of the leaf type *AfAf* ceases soon after soil water saturation. The genotype *afaf* is not as sensitive to soil waterlogging because the tendrils are responsible for the major part of assimilation and are less readily injured by waterlogging (Jackson 1985).

The effect of the *afila*-gene on yield is strongly dependent on the genotypic background of the pea. Thus the *afila*-gene should be transferred to a genetically diverse material if the best selection intensity is to be achieved (Gottschalk and Hussein 1975, Lafond et al. 1981). The restricted leaf area of the *afila*-genotype does not lower the seed yield because less lodging and a more even light distribution compensate for the loss of leaf area. Nearly isogenic *afila*-genotypes have a better yield capacity than normal leafed types (Kielpinski and Blixt 1982, Cousin et al. 1985). The genotype *afaf. stst* is inferior in yield compared to *afila*-peas (Snoad 1985), but its yield capacity can be raised by increasing stand density (Lafond et al. 1981). In variety trials carried out in the Nordic countries the best *afila*-peas have proved to have as good a yield as the best leafed varieties (Johansson 1984, Stabbetorp 1984, Hovinen 1984, 1985).

Within the pea-family, there are no examples where the standing ability would be based on stem rigidity. Quite the opposite, the plants avoid lodging by attaching their tendrils on neighbouring plants (Smartt 1976). The genotype *afaf* is the most extreme in this respect and the most effective at combatting lodging. Leaflessness is a distinct form of plant "architecture" (Adams 1982), which involves the advantage of less lodging. The normal leafed pea generally lodges during the generative growth phase when the pods are starting to become heavy. The *afila*-pea does not lodge until near maturity (Kivi 1979, Makasheva 1983, Kielpinski and Blixt 1982, Hovinen 1984). The genotype *afaf. stst* is even more lodging resistant than the *afila*-genotype (Snoad 1974, 1985, Hedley et al. 1983, Snoad et al. 1985). The effect of the gene *af* has been compared to the effect of the "Norin" genes in wheat breeding (Kielpinski and Blixt 1982).

The microclimate inside the *afila*-pea stand is drier than in normal leafed pea stands. This probably restricts the spread of foliage diseases (Snoad 1974, Norman 1982). On the other hand, the presence of more tendrils can cause problems, because tendrils are more susceptible than leaves to Downy mildew (*Peronospora viciae*) (Heath and Hebblethwaite 1984). Small *afila*-pea plants are more susceptible to frost than the plants of normal leafed peas (Étévé 1985). Some *afaf. stst* genotypes are more sensitive to herbicides than leafed varieties. However, the poor ability to compete with weeds means that herbicides have to be used when growing Filby- and *afila*-types (Knott 1985). The *afila*-character does not hinder good protein production and early maturity properties (Hovinen 1985).

Information about the effect of different genes on yield has been obtained from genebank information. The yield models have been calculated by computer (Blixt 1978). Having a strong effect on stand structure (Adams 1982), the gene *af* is regularly incorporated in the ideotype of the pea plant (Pyke and Hedley 1985, Snoad 1985). Ideotype is a concept which changes depending on the needs (Blixt and Vose 1984). Thus the *af*-gene may not always give any yield advantage.

However, most plant breeders have been

eager to include the gene *af* either with or without the gene *st* in genotypes of new varieties in the eighties (Kielpinski and Blixt 1982, Johansson 1984, Kivi 1984, Hovinen 1985, Snoad 1985).

The experimental base for this work was breeding material for developing varieties. The main trials in this study were grown at two nitrogen application levels for the purpose of studying the differences between *afila-* and some conventional genotypes in response to nitrogen fertilizer. Genetic variability was broadened by carrying out distant crosses. Root sampling and the measurement of morphological characteristics were done with the object obtaining more information about the effects of the *af*-gene. The variability in protein content was studied in detail in order to determine whether breeding for protein productivity was feasible. The relationships between the yield and associated factors were studied by statistical methods.

This study deals partly with the same problems as the earlier works of the author: "Mixed cropping — a method for better yield stability", 1983, in Finnish and "Breeding of pea for protein crop", 1985, also in Finnish. The pea breeding work has also been presented in the serial publication "Five-Year Report of Hankkija Plant Breeding Institute" (in Finnish) in 1975, 1980 and 1985. The characteristics of the released varieties, developed during the course of the program, are described in detail in the communications of Hankkija Plant Breeding Institute (in Finnish): Hankkijan Hemmo-pea, Communication No. 6, 1982; Hankkijan Heikka-pea, Communication No. 10, 1983; Hankkijan Tammi, a semileafless pea, Communication No. 13, 1984; Pika, Panu and Helka, new peas, Communication No. 27, 1987. For simplicity, the prefixes "Hankkijan" of the variety names have been omitted later in this publication. Prefixes of breeding line numbers refer to breeding institutes or genebanks:

Hja = Hankkija Plant Breeding Institute, Finland
J.I. = John Innes Institute, England
Jo = Agricultural Research Centre, Department of Plant Breeding, Jokioinen, Finland
L = H. Lamprecht, Weibullsholm Plant Breeding Institute, Sweden
Sv = Svalöf AB, Sweden
WIR = The N.I. Vavilov All-Union Institute of Plant Industry, Soviet Union

A. Material and methods

1. Trial sites and field experiment conditions

The majority of the variety trials and complete production of the breeding material were carried out at the Anttila Experimental farm of the Hankkija Plant Breeding Institute. The farm is situated thirty kilometers north of Helsinki (60.42°N, 25.03°E). Variety trials were also performed at the Nikkilä Experimental farm of the Hankkija Plant Breeding Institute, twenty kilometers northeast of Tampere, and at the South-West Finland Research Station of the Agricultural Research Centre, thirty kilometers northwest of Turku. Small variety trials were carried out at the privately owned Viskaali farm, thirty kilometers southwest of Oulu.

The trials and the breeding material were grown in all years on a nutrient rich clay soil with high pH value at Anttila (Table 1). The trials at the South-West Finland Research Station were also on clay soils. The trials in Nikkilä were on silt soils, and the trials in Viskaali on fine sand soils.

The weather conditions during the experimental period were very changeable (Table 2). The variety trials at Anttila in 1981 were har-

Table 1. Properties of the surface soils in the variety trial fields, and seeding times at Anttila.

Year	Soil type	pH value	Extractable nutrients, mg/l			Sowing date
			Ca	P	K	
1979	Sandy clay	5.6	2600	11	170	15.5.
1980	Sandy clay	6.3	2370	15	155	14.5.
1981	Sandy clay	7.0	3850	22	195	21.5.
1982	Muddy clay	6.6	1900	13	142	11.5.
1983	Muddy clay, sandy	6.4	3200	16	135	10.5.
1984	Sandy clay	6.2	2700	17	105	18.5.
1985	Sandy clay	6.5	3021	21	148	21.5.
1986	Loamy clay	6.5	2800	33	239	18.5.

Table 2. Mean temperature and precipitation during the growing season at Anttila.

Year	May		June		July		August		September	
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
1979	11.1	31	16.4	48	14.9	147	16.1	37	9.7	63
1980	7.3	56	17.4	38	17.0	49	15.1	85	10.8	63
1981	11.4	26	13.3	123	17.2	111	14.2	84	10.4	44
1982	9.6	28	12.1	58	17.7	26	16.0	112	10.4	27
1983	12.0	38	14.0	66	18.1	28	15.8	48	11.8	98
1984	13.1	35	14.3	71	15.5	99	15.0	24	10.1	126
1985	9.8	64	13.9	63	16.0	73	16.4	84	9.5	58
1986	11.3	44	17.3	23	17.3	67	13.9	127	7.2	71
1931—60	8.6	39	14.2	47	17.1	72	15.4	71	10.2	62

vested only partly due to soft soil conditions, and they are not included in the trial results.

2. Breeding material in 1970—78

The material available for pea breeding was almost extinct at the end of the sixties, and only 16 lines were left in the variety trial stage in 1970. In order to develop new material, 27 varieties were obtained for use in crosses from the genebank of the Vavilov Institute. The most important parental variety was Usatyj 5 (k-5110), the source of the *af*-allele (Makasheva 1983) for the main part of the breeding material used in this work. An early and small seeded Turkish variety (k-2225) was the other important gene source in this material. A Dutch variety (Proco) was used for its earliness in many crosses, and later proved to be very valuable. An English variety (Filby) has been an important origin of *af*- and *st*-alleles (Snoad 1974) since 1978. Since the breeding of semi-high varieties was the main goal in crosses made during the seventies, many low-stemmed Dutch and English varieties were used as cross parents. The other parental variety was usually some well established own line. A total of 58 crosses were made in 1970—78.

A combined population-pedigree method was applied as the breeding method, the first single plant selection being performed in generation F_3 or F_5 and the last one in F_6. Breeding material was grown each year in the field in the form of line rows, small (multiplication) plots, preliminary trials and main trials. 69 lines, developed from the breeding material in 1970—78, were still left in the yield trials in 1986. Some 28 of these lines have also been incorporated in various trial programs in many European countries.

3. Breeding material in 1979—86

In order to create a very broad genetic base for the breeding material (Makasheva 1983), a lot of foreign material was incorporated in the breeding population during the period 1979—86. The planning of every single cross was based on the idea that early, leafless and semi-high stemmed plants must be easily obtained from segregating populations. Early mutants, *af-*, *fa-* and *fas*-allele (stem fasciation) sources (Blixt 1972, 1978 c), were obtained from the Weibullsholm gene bank. A resistance breeding programme was started simultaneously to incorporate disease resistance into the material described above (Laitinen 1985). 13 varieties and lines were obtained from the John Innes Institute. They contained resistance alleles against *Fusarium oxysporum, Peronospora viciae, Erysiphe pisi* and *Ascochyta* ssp. diseases (Matthews and Dow 1983). Varieties ordered from the genebanks of the Vavilov Institute, Zentralinstitut für Genetik und Kulturpflanzenforschung, Gatersleben, DDR and Institute for Plant Production and Qualification, Tápiószele, Hungary, were also used as resistance sources. They also increased the genetic variability of the breeding material. Some 355 crosses were made during the study period.

The pedigree method of selection was used with this material. Experience has shown that selection cannot be carried out in dense stands, because low stemmed, leafless genotypes are weak competitors and rapidly disappear from such populations. Effective selection for disease resistance was also feasible from the space-planted pedigree line rows. The single-seed-descent (SSD)-method could have been adapted to speed up the work (Hedley et al. 1983). The material would, however, have been difficult to observe and handle in the F_5-generation because of the absence of early selection. Back-cross programmes were not used. The selection work done in accordance with the pedigree method and the structure of the material are presented in Fig. 1. F_1-generations were cultivated during the winter.

Single plant selection was predominantly done in the F_2—F_5 generations during the generative growth phase on the basis of plant morphology. Late or long stemmed plants and plants with disease symptoms were discarded.

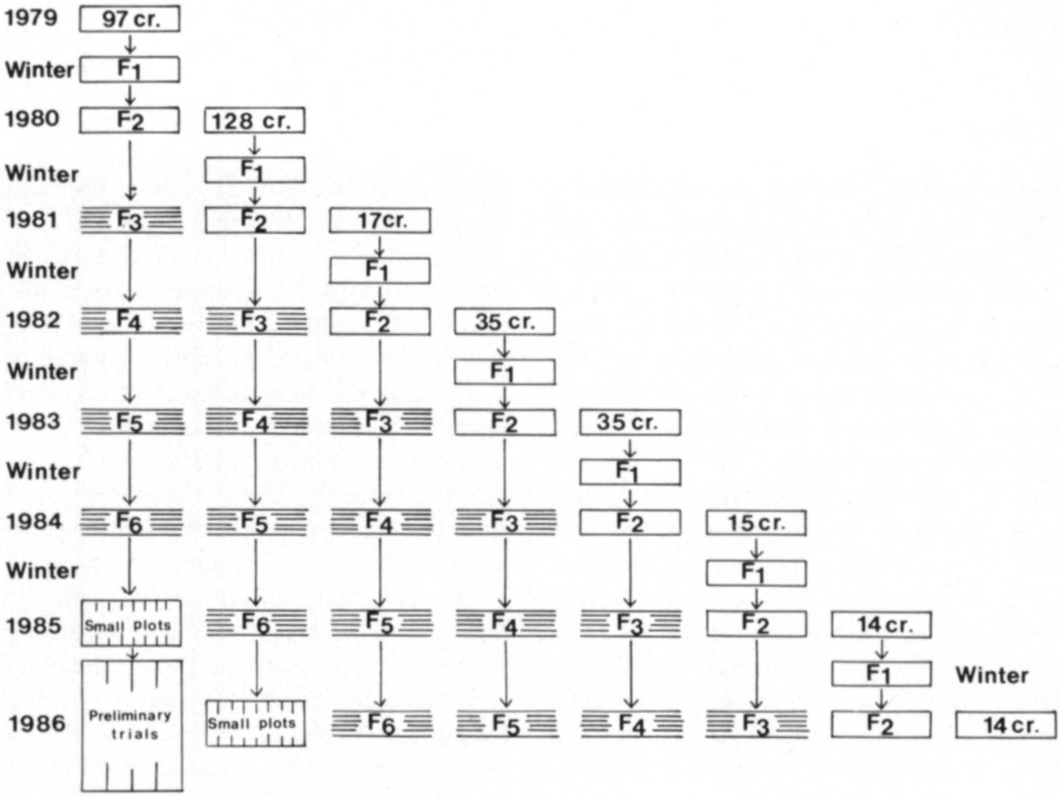


Fig. 1. Breeding procedure by pedigree system.

Leafed peas were selected only in exceptional cases due to some special property.

Special attention was paid to stem rigidity. The seed yield of all single plants were examined during the winter. Plants infected by *Ascochyta* ssp., as well as all marrowfats (*rr*. genotypes, GELIN 1960) and seeds in poor shape were discarded in this connection. A relatively small seed size was favoured. Seed colours were registered, particularly dark green mutants (BLIXT 1972, KIVI and HOVINEN 1974). Similarly *mifo*-genotypes, seeds with close standing, small and shallow impressions (LAMPRECHT 1962) were selected as a special group. The expressivity of the *def*-allele, which results in the development of a much thicker funicle with a greater area of attachment to the seed (SNOAD 1985), was surveyed in some cross pedigrees before plant threshing by opening the pods.

The annual number of single plant pedigrees in the field varied from 6 000 to 10 000 depending on the number and nature of the crosses.

4. Field trials of young breeding material

The multiplication plots for pure lines were unreplicated, and were seeded using the yield threshed from single plant pedigree rows. The size of the plots was either 3.7 or 8.0 m^2 depending on the seed quantity obtainable. The multiplication plots were also cultivated in mixed stands with spring wheat as in the preliminary trials. The number of harvested lines was 163, 167 and 230 in 1983, 1984 and 1985, respectively. The aim of growing multiplication plots was to obtain more seeds for establishing replicated preliminary trials. A further aim was to discard inferior lines on the basis of field observations.

Single plant pedigrees of generations F_3—F_6 were grown as line rows. A sparse wheat stand was seeded to support the crop. The selected single plants and line rows were harvested by hand. The line row yields from the F_6-generation were used as the seed for the following year's multiplication plots. 533 line rows were harvested in 1984 and 425 in 1985. The crude protein contents of all the lines were analyzed.

After 1980, the F_2-populations were grown together with a very sparse wheat (50 seeds/m^2) stand acting as the supporting crop, on plots 8 m^2 in size. The seeding rate for pea was also low, 20—40 seeds/m^2. The idea was that long stemmed plants would not shade dwarf type plants too much. In addition, single plant selection was also easier to perform.

5. Yield trials

The main trials were established in 1979—86 at Anttila using lattice designs (Cochran and Cox 1960). The plot size was 8 m^2 and the stands threshed as a whole. Peas were cultivated in pure stands. The number of varieties varied from 25 to 42.

The main trials involved both the varieties of the Finnish official trial and the author's best own lines. The basic fertilizer in all years was NPK fertilizer (2.0—7.9—12.4) at a level of 800 kg/ha. All fertilizers were placed at a depth of 8—10 cm according to common practice in Finland (Elonen 1983).

Nitrogen fertilizer (27.5—0.0—0.0) was applied to two of the four replications at the rate of 233 kg/ha in 1979—1985. Thus the varieties were grown at a low nitrogen level of 16 kg and a high nitrogen level of 80 kg. Efficiency of biological nitrogen fixation in the varieties was thus evaluated at two nitrogen levels. Varietal differences in biological nitrogen fixation have previously been demonstrated (Hobbs and Mahon 1983, Köylijärvi 1984, Cousin et al. 1985). The seed rate was 120 germinating seeds/m^2, with the exception of the so-called Filby genotype *afaf. stst* where the seed rate was 140 seeds/m^2 (Anon. 1979). The trials were drilled using an "Øyjord" type plot drill, and were harvested by plot combines equipped with crop lifters. The varieties were threshed in accordance with the date of maturity.

The variety trials at the South-West Finland Research Station, Nikkilä and Viskaali were carried out in accordance with the same experimental practice as the main trials. However, no nitrogen was applied.

So-called preliminary variety trials were established in 1983—85 at Anttila as mixed stands with a sparse cereal component. The aim was to evaluate new pea lines when grown in mixtures (Hovinen 1983 b, Sundman and Varis 1983). Another argument for using mixed stand cultivation was technical; threshing of a mixed stand plot takes only half the time needed to thresh a pure stand plot. The yield from a mixed stand is also of higher quality than that from a pure stand (Hovinen and Varis 1983). Two of the four replications were drilled with the following seed mixture: 100 pea seeds plus 100 spring wheat seeds per 1 m^2. Oats at the rate of 83 seeds/m^2 was the cereal component in the other two replications. The experimental design of the preliminary trials was similar to that of the main trials. Nitrogen was given at one level only: NPK fertilizer (2.0—7.9—12.4) at 800 kg/ha. Oats was selected for the cereal component because it has been shown to nick well with peas in earlier studies (e.g. Hänninen 1956). Wheat was chosen as the other cereal since preliminary experiments had indicated that it is the best crop for supporting peas. It also does not shade the peas too much. Preliminary trials consisted of breeding lines, which were new and mainly used for the first time in yield trials. Standard varieties were included in all the trials. The number of varieties was 112, 136 and 128, in 1983, 1984 and 1985, respectively. The varieties were divided into two trials each year. The preliminary trial in 1986 partly failed as a result of bad harvesting conditions.

6. Seed treatment and plant protection

None of the seed was treated with fungicides because, according to earlier experiences, it has not been found to improve establishment. The seeds were not inoculated with *Rhizobium* because earlier information was available about the effectiveness of the *Rhizobium* populations in nitrogen fixation in the trial fields (HOVINEN 1983 b, KÖYLIJÄRVI 1984). Weeds were suppressed using dinoseb. In some years pea aphids (*Acyrthosiphon pisum*) and pea moth (*Cydia nigricana*) had to be controlled by spraying.

7. Field experiment observations

The following observations were made during the growing season in all yield trials and multiplication plots: date of establishment, relative growth rate of seedlings, start and end of flowering, height of crop, lodging (2—3 times during the generative phase), date of maturity and harvesting date. Observations of purity, morphology and overall appearance were done in the yield trials. The presence of diseases was checked, although not systematically. Morphology, maturity and disease resistance were noted for selection criteria in connection with single plant selection in the pedigree breeding system.

It must be emphasized that the observations and yield results are from plant stands, not from spaced grown plants. This practice was followed because competition between plants is an important factor present in normal pea cultivation.

8. Root and shoot samples

Root and shoot samples were taken from the varieties in the main trials in 1979—82 at the beginning of flowering in the first half of July. Between ten to twenty plants, roots included, were lifted from all plots. All the plants at a distance of 0.5—1.0 metres from the end of the plots were taken as samples. The roots were washed, the abundance of root nodules was estimated and the plants oven dried. The dry weight of the roots and shoots was recorded separately. Crude protein contents were analysed by the Kjeldahl method. Varietal differences in nodulation abundance have earlier been found (GELIN 1960, GELIN and BLIXT 1964, JACOBSEN and HENNINGSEN 1980), and in this study the nodulation of leafless vs. normal peas was compared. The size of the roots and shoots and their nitrogen content were also determined.

9. Harvest index measurements

The shoots of 10—15 plants were taken in 1984—85 from all the plots of the main trials for harvest index evaluation. The shoots were cut off close to the soil surface. The sampling time was close to yellow maturity or, at the latest, at full maturity. Sampling was begun at a distance of 1 meter from the end of the plot, and all the plants along a short section of the two middle rows included. The samples were dried and weighed air dry. Seed yields were weighed after threshing and the harvest indices, percentage of seeds out of the total aboveground biomass, were calculated. There are not many references concerning the harvest indices of afila-peas in the literature (KERTESZ 1984, STOY 1984).

10. Morphological measurements of shoots

In 1985 two plants of all 42 varieties were taken at random for morphological measurements. Stem thickness was measured in the thinnest direction at the base and at the central part. The width and length of the other half of the fifth stipule from the top were measured. The total number of nodes and number of fertile nodes were counted. The number of seeds in each pod was counted on two plants only in one replication.

Similar morphological measurements were also done in the mixed stand (preliminary trial) in the same year. 51 varieties were measured, nearly all of which were different from the main trial. The number of seeds in each pod was not counted.

11. Quality investigations

Crude protein content was the central characteristic in the quality research. However, the resources were not sufficient to investigate this aspect in single plant yields. After 1984 the crude protein content was analyzed from the yields of F_6-plant pedigrees (line rows). Protein analyses were always done from the yields of multiplication plots and yield trials. The lines with the most inferior protein content were discarded on the basis of analysis of the F_6-line row or multiplication plot yields. The crude protein content was first analyzed by the Kjeldahl-method. After 1983 it was replaced by NIR-analysis, calibrated each year with Kjeldahl-determinations. The protein content was calculated on the basis of a moisture content of 15 % in the seeds.

Thousand seed weight was determined from the yields of all multiplication plots and yield trials. External seed quality analysis was performed in accordance with the instructions of official trials. The percentage of first quality or faultless seeds was recorded. Cooking tests were also made from the main trial yields in accordance with official instructions.

All yields of the multiplication plots and yield trials were examined visually during the winter. Colour, form, smoothness, size, equality of size, maturity and damage caused by diseases were recorded. Those lines with a high germination in tests were favoured in the selection work on the lines in yield trials.

12. Statistical analyses

The variety trials were arranged as randomized block, splitplot or lattice designs (Cochran and Cox 1960). Analysis of variance, student's t-tests, correlation analyses and Tukey's tests (Snedecor 1956) were computed. "Statgraphics" (Polhemus 1984) programmes, "Exploratory Data Analysis" and "Regression Analysis" were used for graphic and statistical treatment of the variety trial results. Results of exploratory data analysis are presented as notched whisker plots (first in Fig. 2). A whisker plot displays a solid box between the upper and lower quartiles, a central line at the median, and whiskers out to the extreme largest and smallest values. Any points at a distance from the box greater than 1.5 times the length of the box are plotted as separate "adjacent" values. The display is useful in indicating skewness (note the larger distance from the median to upper quartile compared to the lower in Fig. 2, 16 kg N/ha). The width of each box has been made proportional to the square root of each sample size. Also, a "notch" has been placed around each median. The overlapping notches for factors in Fig. 2 indicate no significant difference between nitrogen applications at the 5 % significance level. Pair comparisons of varieties were computed by a programme developed by Rekunen (1978). The same programme also computed the yield level comparison of Finlay-Wilkinson (1963) between varieties. All correlations in statistical analyses were phenotypic correlations.

B. Results and Discussion

1. Factors affecting pea yield and quality

1.1. Pure stands

1.1.1. Seed yield

During the period of the trials the mean yield of the pea varieties was 4506 kg/ha (Table 3). Under similar conditions in the field most of the barley varieties had a mean yield of between 5000—6000 kg/ha (Aikasalo and Kesälä 1985). In the Finnish official pea trials the best varieties had a mean yield of 3500—4200 kg/ha during 1978—86 (Mustonen et al. 1987). For comparison the best Finnish variety reached a mean yield of only 2167 kg/ha in old experiments at Jokioinen in 1947—62 (Inkilä 1963). Stoy (1984) reported that the mean yield is 3000—3500 kg/ha in large scale cultivation in the nordic countries. The average yields of the main trials must be considered high in comparison with the results from other sources. The yield difference compared to barley was smaller than expected.

The higher level of nitrogen application did not significantly increase the seed yield (Fig. 2, Table 4). This deviates from the results of Köylijärvi (1984), in which fertilizer nitrogen increased the yield up to a level of 100 kg/ha. In Swedish experiments applied nitrogen had an insignificant effect on the yield (Bengtsson 1984 a). A similar result was obtained in Finland in connection with experiments on biological nitrogen fixation (Hovinen and Varis 1983). The results of the present study indicate that abundant nitrogen application does not, on the average, increase the yield of pea varieties. At the same time it should be borne in mind that two nitrogen rates only are not sufficient to determine the optimum amount of fertilizer. There were no possibilities to calculate interactions between a variety and nitrogen application, because nearly all the varieties were changed during the experimental period.

The difference between the yields of normal leafed (*AfAf*) and afila-peas (*afaf*) was not significant (Fig. 3). Instead the Filby-type (*afaf. stst*) had clearly lower yields than the other leaf types. Previously, for instance,

Table 3. Statistical data of varietal phenotypic characteristics. Main trials 1979—80, 1982—85. 388 observations.

Characteristic	Mean	Standard deviation	Range
Seed yield kg/ha	4506	977	2110—7450
Protein yield kg/ha	989	241	410—1841
Flowering period d	22.6	9.7	5.0—51.0
Growing time d	100.7	7.1	85.0—122.0
Stem height cm	78.6	23.6	31.0—167.0
Lodging-%	45.8	25.5	0.0—100.0
Crude protein	22.1	3.1	16.0—29.3

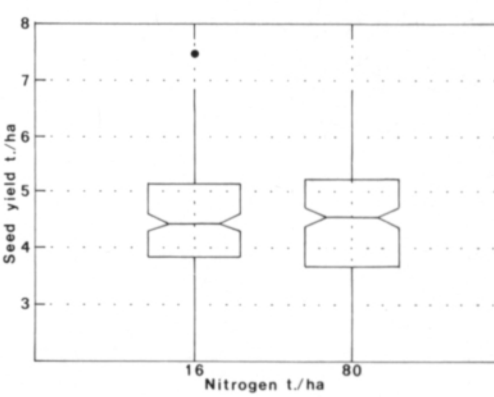


Fig. 2. Seed yield at two nitrogen application levels. Main trials 1979—85.

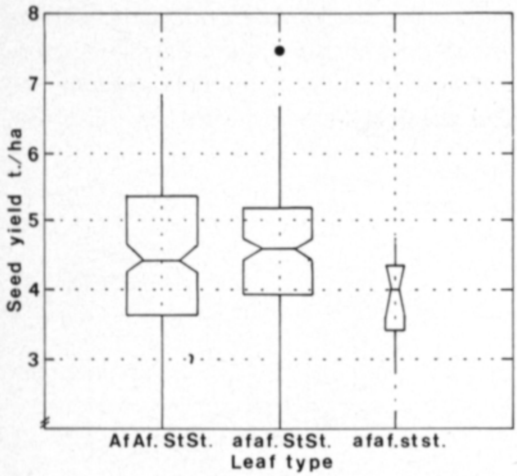


Fig. 3. Seed yield of three leaf types. Main trials 1979—85.

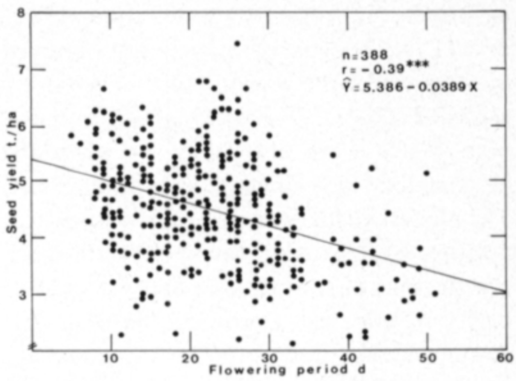


Fig. 4. Relationship between flowering period and seed yield. Main trials 1979—85.

KIELPINSKI and BLIXT (1982) as well as COUSIN et al. (1985) found that the afila-type gave a better yield than the normal leafed type. Their results and the results of the current study have much in common, although the yield difference was not significant in this study. The Filby-type, which was mainly represented by Filby itself, had an unexpectedly good yield relative to its small leaf area. Its yield variation was less than that for other varieties, and its top yield was 4740 kg/ha. SNOAD (1985) suggested that Filby can reach a yield level of as high as 5000 kg/ha in large scale farming in England. In the current breeding program, the work is directed at the afila-type because of its generally good yield and possibilities to achieve top yields such as the 7450 kg/ha in this study. Some leafed genotypes which have very good stem stiffness, like "rabbit eared rogue" types (SNOAD 1985), are still kept within the breeding programme, likewise the best yielding Filby-types. The aim is to transfer the Filby-type to various genetic backgrounds in order to increase yield.

Negative correlation was found between the flowering period and yield of a variety (Table 4). The range of the flowering period was usually wide (Table 3). The negative relationship was exclusively a consequence of the long flowering periods, lasting for more than one month, which had an unfavourable influence on the yield (Fig. 4). No clear optimum length for the flowering period was found. The best yield results were found within the range from 9 to 28 days.

Unexpectedly the correlation between the seed yield and growing time of a variety was also negative (Table 4). The average growing time was 100.7 days, but the range was wide

Table 4. Phenotypic correlations between yield, other varietal characteristics and nitrogen application. Main trials 1979—80, 1982—85. 388 observations.

Characteristic	Seed yield	Protein yield	Nitrogen applic.	Leaf type	Flowering period	Growing time	Stem height	Lodging
Protein yield	0.81***							
Nitrogen application	0.02	0.10						
Leaf type	—0.03	—0.24**	0.00					
Flowering period	—0.39***	—0.20**	0.03	—0.14**				
Growing time	—0.31***	—0.12*	0.06	—0.07	0.52***			
Stem height	—0.12*	0.07	0.04	—0.11*	0.63***	0.41***		
Lodging	0.10*	0.38***	0.05	—0.72***	0.01	—0.17**	0.07	
Protein content	—0.19**	0.41***	0.14**	—0.39***	0.28**	0.28**	0.34***	0.47***

and especially skewed in the direction of lateness (Table 3). Top yields were not obtained in cases where the growing time of a variety exceeded 106 days (Fig. 5). On the other hand, poor yields were also obtained when the growing time of a variety remained very short. The highest yields were gained in cases where a variety had a growing time of 91—106 days. For the sake of comparison, the best yielding barley varieties have a growing time of 87—95 days in similar conditions (Aikasalo and Kesälä 1985). The correlation between flowering period and growing time was significantly positive. Length in excess of both prevented top yields being obtained from a variety. Growing time was also positively correlated with stem height.

The correlation between seed yield and stem height was negative, fairly weak but significant (Table 4). For comparison, Kaul (1980) found no significant correlation. It should be noted that the varieties represented a generally semi-high stem height with a mean of 78.6 cm (Table 3). The range was broad, including very long-stemmed varieties, too. In most cases stem heights of above 100 cm were disadvantageous from the point of view of yield formation (Fig. 6). This was caused by other factors connected with stem height such as lateness and problems and losses in harvest. The predominant part of the best yield results were obtained with a stem height of 61—94 cm. Drought sensitivity has been shown to restrict the yielding capacity of extremely short-stemmed varieties (Bingefors 1972, Kivi 1979, Flengmark 1984). When breeding peas for use under Finnish conditions one must therefore aim for a »semi-high» stem covering a fairly wide range from 60 to 95 cm, however.

During the experimental period the average lodging of the varieties was 45.8 per cent (Table 3). Lodging was distributed quite evenly on the scale of 0—100 per cent (Fig. 7). A weak positive correlation prevailed between lodging and seed yield (Table 4, Fig. 7). One explanation for this may be that a large yield makes the crop weighty, which itself will increase lodging. Often a top-yielding variety does not lodge until some days before full maturity, lodging thus not having time to decrease yield. Since high yields have also been

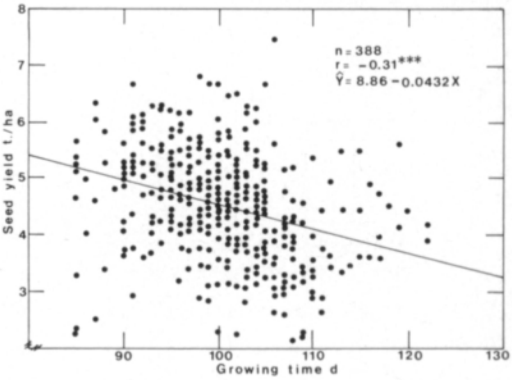


Fig. 5. Relationship between growing time and seed yield. Main trials 1979—85.

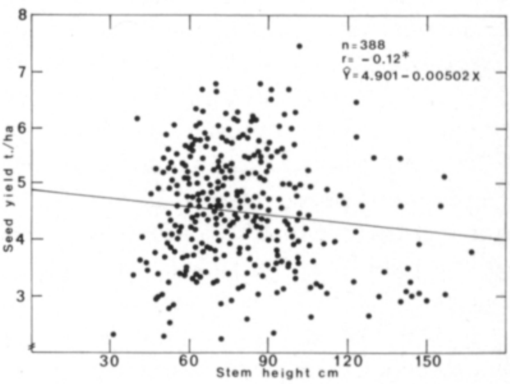


Fig. 6. Relationship between stem height and seed yield. Main trials 1979—85.

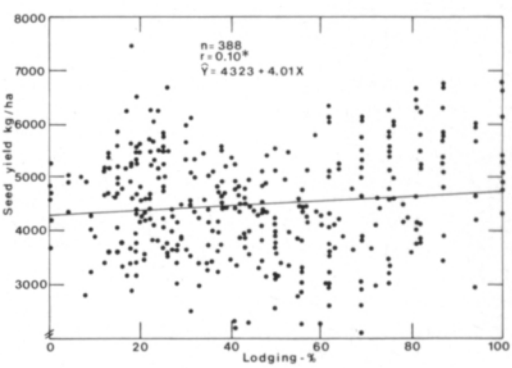


Fig. 7. Relationship between lodging-% and seed yield. Main trials 1979—85.

obtained with a low degree of lodging of 15 to 30 per cent, strong lodging is not a presumption for high yield.

The more lodging resistant a variety is, the greater the change of it giving top yields. Lodging resistance is among the key characters in formulating a pea ideotype (Blixt 1978, Kielpinski and Blixt 1982, Hedley et al. 1983 b, Heath and Hebblethwaite 1984). In this study the Filby leaf type, *afaf. stst,* had the best lodging resistance, followed by afila, *afaf. StSt,* which, in turn, had a better lodging resistance than the normal leaf type (Fig. 8).

The correlation between protein content and seed yield was negative at a significant level, although relatively weak (Table 4). High protein contents were found in the variety trial over a wide range at different yield levels (Fig. 9). A poor yield capacity may be consequence of a high protein content. The converse may also be true: a low protein content can arise from an extremely high yield. Growing conditions during pod fill have in this case favoured the accumulation of carbohydrates in the seeds. The results include a great number of instances where a high yield has been associated with a high protein content; thus selection for high protein does not prohibit a variety from also reaching high yields. Obviously the assimilation of carbon and nitrogen in the pea crop are so closely connected with each other that this will be possible. Varying results have been obtained earlier concerning the correlation between protein content and seed yield. Blixt (1978), Kaul and Garg (1978), Bingefors et al. (1979) and Swiecicki et al. (1981) found that the correlation is negative; Bingefors (1958), Slinkard (1981) and Cousin et al. (1985) verified that no correlation existed. Kielpinski and Blixt (1982) considered that the correlation will be broken in the afila-genotype. To sum up one can state that a weak negative correlation, found in some cases in the pea crop, does not rule out the possibility of a high protein content and high yield.

A yield model was calculated to depict the effects of phenotypic characteristics (see Table 4) on seed yield (multiple regression, stepwise, F-value < 4.0 removed) kg/ha:

$$Y = 7253 - 4.42X_1 + 0.949X_2 - 2.48X_3; \quad R^2 = 0.19$$

where X_1 = flowering period d, X_2 = stem height and X_3 = growing time d. The model explained only 19 per cent of the yield. It is noteworthy that the contribution of protein content and lodging was not strong enough to warrant their inclusion in the model. Part of the yield is dependent on unknown factors, which cannot be incorporated in yield models. The model presented above is not applicable for prediction purposes. The most strongly influenced characters should, however, be taken into account in phenotypic line selection for yield.

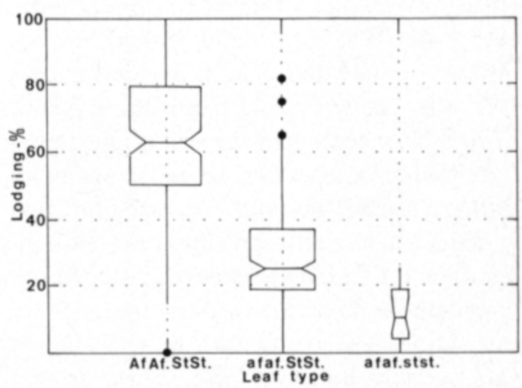


Fig. 8. Lodging-% of three leaf types. Main trials 1979—85.

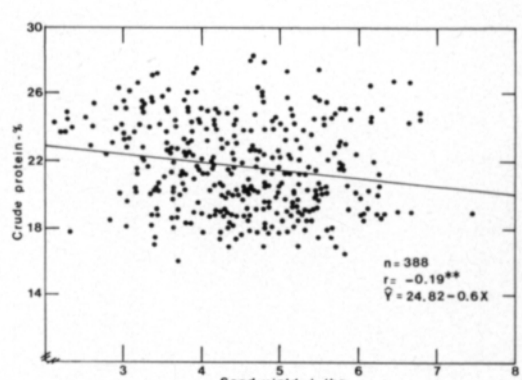


Fig. 9. Relationship between seed yield and protein content. Main trials 1979—85.

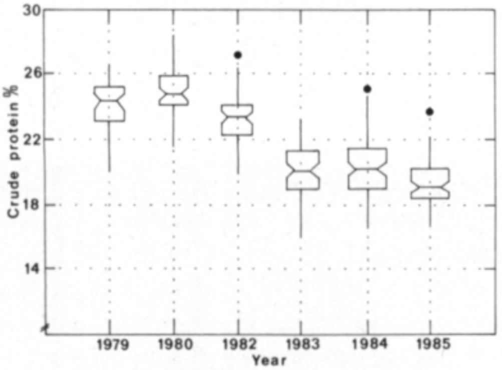


Fig. 10. Protein content in different years in the main trials.

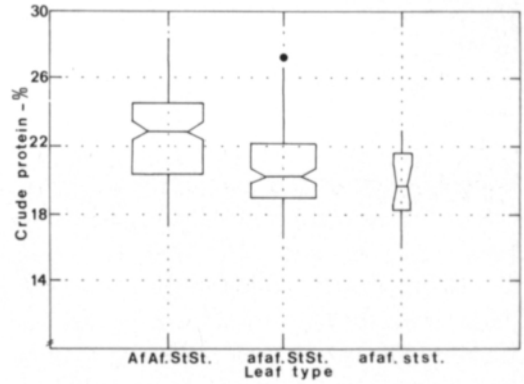


Fig. 11. Protein content of three leaf types. Main trials 1979—85.

1.1.2. Protein content

The range of protein content was wide (Table 3). It was slightly broader than that in the material represented earlier by Pesola (1955), which had a range of 17.6—27.0 per cent. After 1983 the protein content was significantly lower than that in preceding years (Fig. 10). The result might be a consequence of both chance in growing conditions and a transition to varieties that are earlier and more leafless. The leafless (*afaf. StSt* and *afaf. stst*) varieties had a significantly lower protein content than the leafed varieties (Fig. 11). Matthews and Arthur (1985) found a similar result. Other genetic factors of the leafless varieties may, however, influence the protein content more strongly than leaflessness alone.

The higher nitrogen application level significantly enhanced the protein content of the varieties (Table 4, Fig. 12). The protein content improved by one per cent. Biological nitrogen fixation might not have proceeded satisfactorily in all the trials. Extensive experiments in Sweden have indicated that nitrogen application does not increase the protein content (Bengtsson 1984 a). Neither does nitrogen application enhance the protein content of red clover, the other nitrogen-fixing crop of particular importance (Raininko 1968).

The correlation between flowering period and protein content, as well as between growing time and protein content, were positive and significant (Table 4). A long flower-

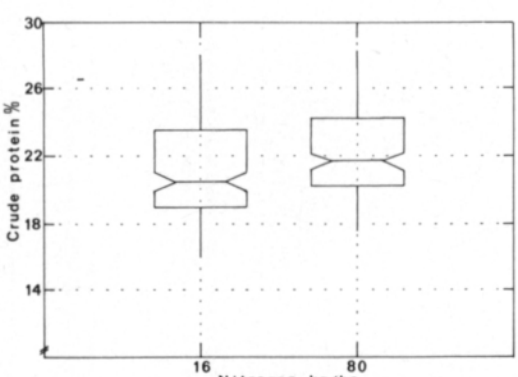


Fig. 12. Protein content at two nitrogen application levels. Main trials 1979—85.

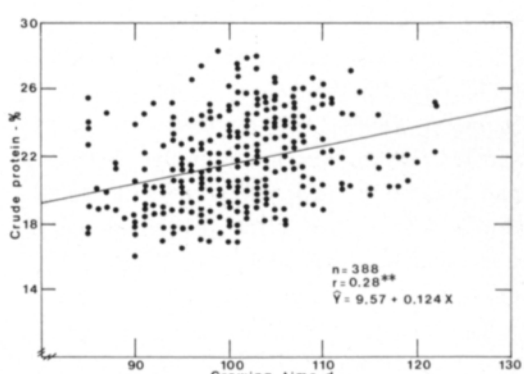


Fig. 13. Relationship between growing time and protein content. Main trials 1979—85.

ing period, when seed development extends over a long period, may favour a high protein content. A lengthening of the growing time had the same effect on protein content (Fig. 13). Biological nitrogen fixation probably lasts longer in such lines. Drought stress, for instance, is no obstacle to nitrogen fixation of long duration under Finnish climatic conditions. Top protein contents did not occur in cases where the growing time of a variety was very short or conversely very long. In selection for protein it is advisable to select a large number of lines with a growing time ranging from 99 to 103 days, where the highest protein contents were found (Fig. 13). A long growing time under the conditions in Sweden has also favoured the development of high protein content (Bingefors et al. 1979 b).

Significant positive correlation was found between pea stem height and protein content (Table 4). Stem heights exceeding 100 centimeters represent, however, so many disadvantages in cultivation that, in spite of the high protein content, they are not suitable for cultivation. Varieties with a good protein content could be selected already from the stem height class, 60—90 cm (Fig. 14). The positive correlation between lodging and protein content was surprising (Table 4). One explanation may be that lodging during the podfilling stage has more of a disturbing effect on the accumulation of carbohydrates than on the accumulation of nitrogen compounds in the seeds.

1.1.3. Protein yield

The average protein yield of the varieties was high, but the range was large (Table 3). Nitrogen application had a tendency to enhance protein yield, although not significantly (Fig. 15). The protein yields of the genotypes *AfAf.* and *afaf.* did not differ significantly from each other (Fig. 16). The genotype *afaf. stst* had a conclusively poorer protein yield than the above two genotypes. Taking into consideration the benefits in cultivation techniques and protein yield, afila-peas are the starting-point for the ideotype of the protein pea.

The correlation between seed yield and protein yield was strongly positive (Table 4). Seed yield explained 65 per cent of the size of the protein yield. A high seed yield proved to be an absolute requisite in breeding for varieties with a top protein productivity. This has also been proposed earlier (Hovinen and Karjalainen 1981, Karjalainen and Hovinen 1981, Matthews and Arthur 1985). The relationship between seed yield and protein yield was rather linear (Fig. 17).

The correlation between protein content and protein yield was highly significant (Table 4). Protein content explained 16.8 per cent of the size of the protein yield. When the aim of breeding is to obtain varieties with as high a protein yield per hectare as possible, then breeding lines with a fairly good protein con-

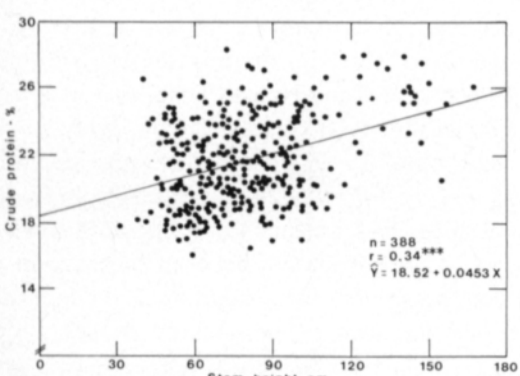


Fig. 14. Relationship between stem height and protein content. Main trials 1979—85.

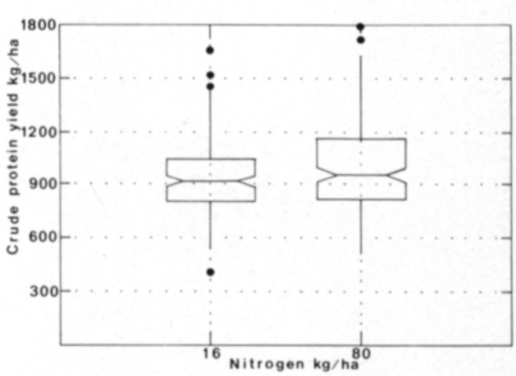


Fig. 15. Protein yield at two nitrogen application levels. Main trials 1979—85.

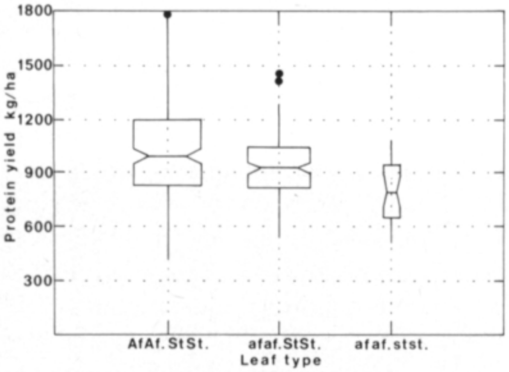


Fig. 16. Protein yield of three leaf types. Main trials 1979—85.

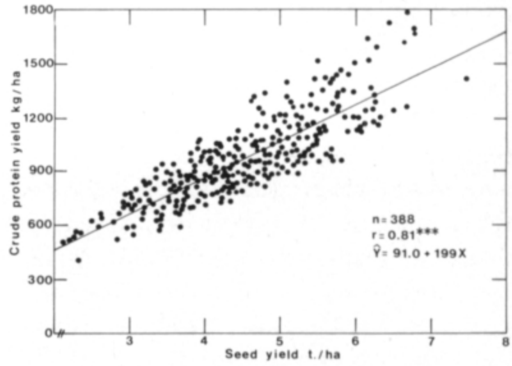


Fig. 17. Relationship between seed yield and protein yield. Main trials 1979—85.

tent must be selected. Top protein yields were found primarily within the range 23—27 per cent protein content (Fig. 18). Selection should be concentrated on this protein content class when breeding for protein peas. Thus varieties with a top protein productivity must posses both a good seed yield and a good protein content. This view is in agreement with an alternative suggested by Swiecicki et al. (1981). On the other hand, Slinkard (1981) and Matthews and Arthur (1985) considered protein content to be of minor importance in breeding for protein yield.

1.1.4. Quality

In addition to the protein content, the means and the ranges of the other quality characters are shown in Table 5. The correla-

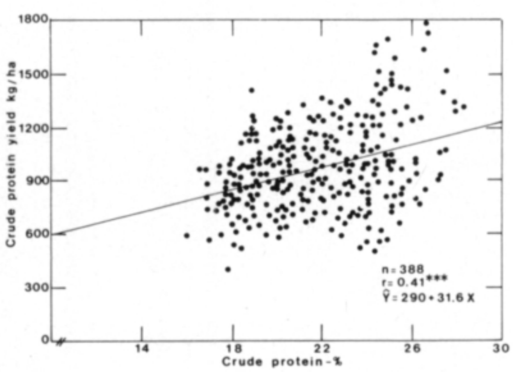


Fig. 18. Relationship between protein content and protein yield. Main trials 1979—85.

Table 5. Statistical data of varietal quality characteristics. Nitrogen fertilization level 16 kg/ha. Main trials 1979—80, 1982—85. 194 observations.

Characteristics	Mean	Standard deviation	Range
Crude protein-%	21.6	3.2	16.0—28.9
Thousand seed weight g	237	57.1	123—417
First class seeds %	67.8	18.5	15—98
Cooking rate	73.0	19.7	1—100

tion coefficients between these and the agronomic characteristics are given in Table 6. The quality characteristics have been analysed only for the nitrogen level of 16 kg N/ha.

The thousand seed weight of the varieties varied greatly. There was no correlation between seed size and seed yield. Thus seed size was of no importance as a yield factor, because the correlation between it and the number of seeds in a pod is negative (Blixt 1978 b). Pyke and Hedley (1982 b) also considered the effect of seed size on yield to be small. Varieties with a long flowering period, as well as long-stemmed and easily lodged varieties, had a tendency to possess small seeds. The correlation between protein content and seed size was negative at the highly significant level. Bingefors et al. (1979 b) also found a similar result. A very large seed size can be an obstacle in breeding for a good protein variety. On the other hand, Cousin et

Table 6. Phenotypic correlations between yield, agronomic and quality varietal characteristics. Main trials 1979—80, 1982—85. 194 observations.

Characteristic	Seed yield	Protein yield	Leaf type	Flowering period	Growing time	Stem height	Lodging	Protein content	Tsw.	First class
Protein yield	0.77***									
Leaf type	0.00	—0.25**								
Flowering period	—0.35***	—0.15*	—0.15*							
Growing time	—0.27**	—0.08	—0.08	0.52***						
Stem height	—0.55***	0.04	—0.09	0.67***	0.40***					
Lodging	0.03	0.38***	—0.70***	0.08	—0.10	0.08				
Protein content	—0.19**	0.47***	—0.41***	0.31**	0.26**	0.33***	0.53***			
Tsw.	0.07	—0.13	0.18*	—0.51***	—0.13	—0.45***	—0.21**	—0.32***		
First class	0.24**	0.21**	0.02	—0.25**	—0.69***	—0.05	0.15*	0.01	—0.09	
Cooking rate	0.28**	0.18*	—0.03	—0.11	0.02	0.05	—0.17	—0.12	0.27**	0.01

al. (1985) and Abou-Salha (1986) did not find any corresponding correlation.

The correlation between first class or perfect seeds in external appearance and seed yield was significantly positive. A similar correlation was found between first class and protein yield. The difference in the proportion of first class seeds between the leafed and afila-varieties was not significant, although it was higher than expected in the former case (Fig. 19). The highest proportion of first class seeds was found in the yield of the Filby-type. Long-lasting flowering and late maturity of a variety were connected with yield of poor external quality. The positive correlation between lodging and the proportion of first class seeds was unexpected. It may be that the early varieties producing a yield of high quality tended to lodge early. There were no correlations between protein content or seed size with the proportion of first class seeds.

The cooking rate was positively correlated with seed yield and protein yield. Thus the good yielding varieties also tended to have a good cookability. The normal leafed varieties produced a yield which had an almost significantly better cookability than the yield from the afila-varieties (Fig. 20). The varieties of the Filby-type also cooked well. Flowering period, growing time and stem height were of no importance as regards cooking rate. On the other hand, lodging had a detrimental effect on the cooking rate. The correlation between

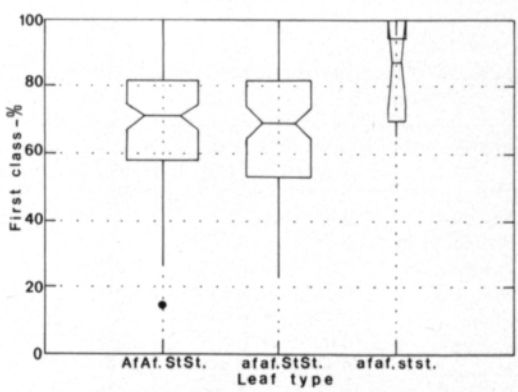


Fig. 19. Proportion of first-class seeds of three leaf types. Main trials 1979—85.

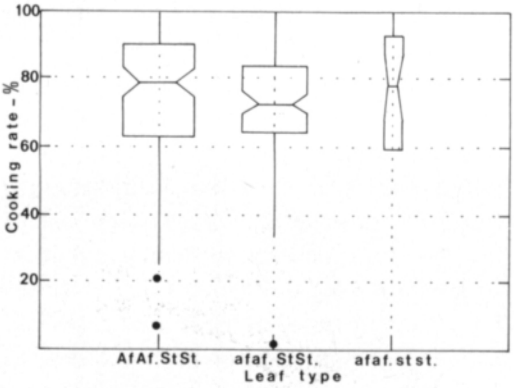


Fig. 20. Cooking rate of three leaf types. Main trials 1979—85.

protein content and cooking rate was insignificant. BINGEFORS (1959) also found no correlation. Seed size and cooking rate were significantly positively correlated. This is an important observation as far as the search for suitable pea types for human consumption is concerned.

1.2. Mixed stands

1.2.1. Total yield

The means and ranges of the varietal characteristics of the mixed stand trials are shown in Table 7, and the corresponding correlation coefficients in Table 8. In comparison with pure stand cultivation (Table 3), the total yields of the mixed stands were higher. The range of the total yield was narrower in the mixed stand than that in the pure stand. Top yields were higher in the pure stands. Cultivation in the mixed stands was more stable, with a C (Coefficient of variation) of 15.2 per cent compared to 21.7 per cent in the pure stands. Many authors have indicated an improvement in yield stability following mixed cropping in northern conditions (HÄNNINEN 1956, HOVINEN 1983 b, SUNDMAN and VARIS 1983). The total yields were predominantly composed of pea seeds. As a result, the pea yield explained 78 per cent of the size of the total yield. (Fig. 21). The characteristics of the pea variety had a decisive effect on the total yield. SAASTAMOINEN (1984) obtained a similar result.

No relationship was found between the growing time and total yield of a variety. On the contrary, pea stem height and total yield were positively, although weakly correlated. However, some long-stemmed varieties had a poor showing in the mixed cropping (Fig. 22). A pea variety should grow high enough to be

Table 7. Statistical data of varietal agronomic and quality characteristics in mixed cropping trials in 1983—85.

Characteristic	Mean	Standard deviation	Range
Total seed yield kg/ha	4713	716	2180—6650
Pea seed yield kg/ha	3962	757	1300—6050
Protein yield kg/ha	899	156	370—1440
Pea growing time d	98.7	7.1	81—120
Pea stem height cm	74.9	17.0	45—160
Lodging-%	19.5	20.3	0.0—93.0
Pea crude protein-%	20.2	1.2	16.9—24.2
Pea thousand seed w.g	213	38.8	100—319

Table 8. Phenotypic correlations between yield and varietal characteristics. Mixed crop trials 1983—85. 365 observations.

Characteristic	Total seed yield	Pea yield	Protein yield	Growing time	Stem height	Lodging	Protein content	Tsw.	Leaf type
Pea yield	0.88***								
Protein yield	0.88***	0.88***							
Growing time	0.07	0.27**	0.27**						
Stem height	0.18**	0.25**	0.31**	0.56***					
Lodging	—0.15**	0.13*	0.02	0.16**	0.08				
Protein content	0.09	0.11*	0.35***	0.46***	0.52***	0.06			
Tsw.	0.35***	0.25**	0.29**	—0.14**	0.12*	—0.26***	0.16*		
Leaf type	—0.15**	—0.18**	—0.22**	—0.05	—0.23**	—0.35***	—0.28**	—0.02	
Seed colour	—0.21**	—0.17**	—0.13*	0.06	0.05	0.10	0.01	—0.30	0.23**

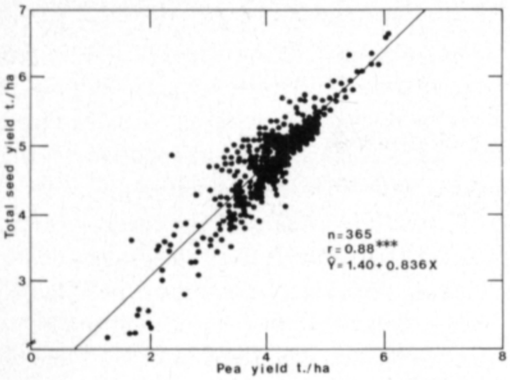


Fig. 21. Relationship between pea yield and total seed yield. Mixed cropping trials 1983—85.

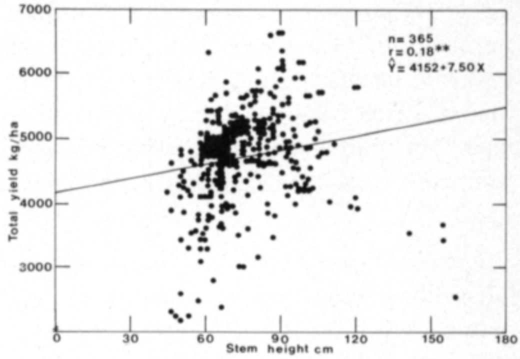


Fig. 22. Relationship between stem height of pea and total seed yield. Mixed cropping trials 1983—85.

capable of competing with the cereal in a mixed stand. The most favourable height was approximately from 80 to 100 cm. A pea variety for use in mixed stand cultivation ought to have a stem 10—20 cm higher than that of a variety for pure stand cultivation (compare Fig. 6). Similarly Pesola (1938) and Hovinen (1983 b) took notice of the importance of pea stem height in mixed stands.

Lodging of the varieties was less in the mixed stands than in the correspond pure stands. The correlation between lodging and total yield was significantly negative.

There was no significant correlation between the protein content of a pea variety and the total yield. On the other hand, the seed size and total yield were significantly positively correlated (Fig. 23). This result differs from the result obtained in the pure stand. Obviously large-seeded peas are better able to compete with cereals than small-seeded peas, especially in the early growth stages. This view is supported by Pesola (1942), who showed that very small-seeded peas suffer from a shortage of nutrients during dry springs. A thousand seed weight ranging from 200 to 270 g seems to be favourable for varieties aimed at mixed stands.

The afila-peas were the best producers of total yield of the three leaf types compared (Fig. 24). This is surprising, because one would have expected the leafed varieties to derive more benefit from the supporting crop. Apparently the abundantly tendrilled afila-pea and cereal together form a very lodging-resistant combination, which also possesses a

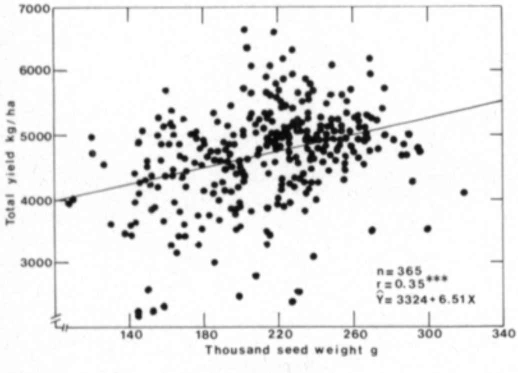


Fig. 23. Relationship between pea seed size and total seed yield. Mixed cropping trials 1983—85.

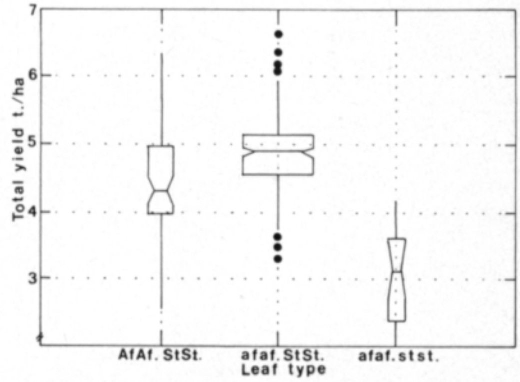


Fig. 24. Total seed yield for three leaf types in mixed cropping in 1983—85.

highly effective crop architecture for carbon assimilation. It can be concluded on the basis of this result that the pea variety for cultivation in mixed stands has to be of the afila-type. The Filby-type varieties, being weak competitors, succeeded poorly in the mixed stand.

The yellow-seeded peas produced lower total yields when grown together with cereal than the green-seeded ones (Fig. 25). No explanation can be given for this at present. However, the yellow-seeded varieties had quite a good competitive ability and, considering only the pea yield from the mixed stand, no difference was found between the two colours (Fig. 26). SLINKARD (1981) found that cotyledon colour did not affect the yield.

A multiple regression model was calculated in order to find the characteristics (see Table 8) which had an effect on the total yield (stepwise, F-value < 4.0 removed):

$$Y = 2927 — 5.63X_1 — 352X_2 + 6.02X_3 + 13.1X_4$$

where X_1 = lodging-%, X_2 = leaf type, X_3 = tsw. g and X_4 = growing time d. R^2 was 0.169, i.e. the model explained only 17 per cent of the size of the total yield. The stem height and protein content did not explain enough to be included in the model. A number of unknown factors must exist that affect the total yield, in addition to those included in the model.

1.2.2. Pea yield

The growing time and stem height of pea correlated positively with the pea component of the total yield. The relatively high-stemmed and late varieties were competitive in the mixed stand, since they usually continue stem growth in July even after the cereal has terminated its growth. A too strong stem growth increases, however, the tendency for lodging.

The correlation between pea yield and lodging of the mixed stand was positive. The positive correlation between the pea yield and its protein content is very pronounced. In mixed stands, very competitive pea genotypes are obviously capable of more productive biological nitrogen fixation than poorly competitive peas. The large seed size was also advantageous for the competitiveness and yield of pea. The good competitive ability of pea also increases its value as a break crop (SIMOJOKI et al. 1986).

The average pea yield was quite high, approaching 4000 kg/ha in the mixed stand. It was lower than that in the pure stand (about 4500 kg/ha), but its variation remained smaller. The pea yield had a C of 19.1 per cent in the mixed stand, and of 21.7 per cent in the pure stand. This result is similar to that found in a number of earlier experiments (HÄNNINEN 1956, HOVINEN 1983 b, BENGTSSON 1984 b).

1.2.3. Protein yield and protein content

The mixed stand produced a high protein

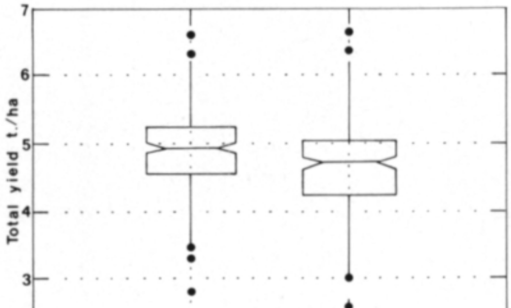


Fig. 25. Total seed yield classified by seed colour of pea. Mixed cropping trials 1983—85.

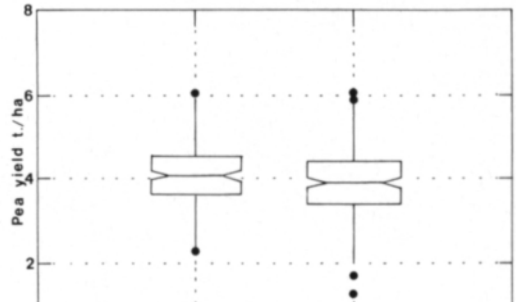


Fig. 26. Pea yield classified by seed colour. Mixed cropping trials 1983—85.

yield of on average about 900 kg/ha. The mean protein content of the total yield of both the pea and cereal components was 19.1 per cent. This is a fairly high value if the yield is to be used as feed directly on a farm. The protein content of cereal increases when it is grown together with peas; this causes the »intercropping effect» in the protein content (VARIS et al. 1981, HOVINEN 1983 b).

The protein yield was almost fully dependent on both the total yield and the pea yield. It was strongly connected to the competitive ability of pea; the correlations between the growing time as well as the stem height of pea and the protein yield were significantly positive. The protein yield was also significantly positively correlated with seed size. The correlation between the protein content of pea and the protein yield was positive and significant. Thus a high protein content was necessary to obtain a high yield of total protein.

Multiple regression analysis was performed in order to identify the factors (see Table 8) affecting the protein yield (stepwise, F-value, < 4.0 removed):

$$Y = -145 - 61.4X_1 + 19.8X_2 + 1.19X_3 + 5.16X_4$$

where X_1 = leaf type, X_2 = protein content -%, X_3 = tsw.g and X_4 = growing time d. R^2 was 0.23, i.e. the model explained only 23 per cent of the protein yield. Lodging, the stem height of pea and seed colour did not explain enough of the variance to be included in the yield model. As was the case with the total yield model, this model was also too weak to be used for predictive purposes. The characters of factors included in the model cannot, however, be ignored in line selection for mixed cropping. It is worth noting that in previous yield models only one component, the pea variety, varied; however, the models in which both components of a mixed stand vary have been suggested for use in breeding (HAMBLIN et al. 1976. WRIGHT 1985).

As was the case with pure stand cultivation, the correlations between protein content and growing time, as well as the stem height of pea, were significantly positive. Similarly, the protein content was positively correlated with seed size. The direction of the correlation was opposite to the result obtained in the pure stand. The pea »mixture»-ideotype is different as regards this characteristic from the ideotype for the pure stand.

2. Morphological characteristics of peas — variation and selection for ideotype

2.1. Stem thickness

In addition to an abundance of tendrils, the stem thickness and strength of peas have an effect on lodging resistance (ESKILSSON 1962, BINGEFORS et al. 1979 a). In the main trials the varieties Hemmo, Allround, Jo 1068 and Finale had the thickest stems as measured at a height of about 1 cm (Table 9). They are all somewhat short stemmed, leafed and, apart from Jo 1068, large seeded. In the preliminary trial the leafed varieties Hemmo and Proco possessed the thickest stem base (Table 10). The long-stemmed variety Cisminskij 242 had a stem base of only medium thickness. The semi-high stemmed afila-peas Hja 52076, Hja 51850 and Sv U 50021 had the thinnest stem base. In the preliminary trial, Hja 52259, Hja 51850 and Helka possessed the thinnest stem base. They are relatively small seeded afila-varieties with a semi-high stem. These results, although only representative of one year, indicate that the genotype *afaf* generally has a thin stem base. The only *stst* genotype, Filby, was also comparatively thin at the base. Nearly significant variability was found, however, within the genotype *afaf*. Of these the late varieties Kimo, Barcota and Tammi had the thickest stem base in the main trial. The early lines Hja 51879 and Hja 52093 were the thickest in the preliminary trial. Even the lowest stipules of the genotype *afaf* are small (SNOAD 1985). This may result in a small assimilating area, thus weakening growth thickness of the stem, as in the genotypes *stst* (PYKE and HEDLEY 1982 a), see Fig. 27 C.

Table 9. Morphological characteristics of 42 pea varieties. Main trial 1985.

Variety	Diameter of stem		Dimensions of stipule		Number of nodes	No. of fertile nodes	No. of seeds/ pod
	Base mm	Central part mm	Width mm	Length mm			
Allround	3.50	4.45	34.7	67.6	15.5	4.5	6.0
Barcota	2.95	4.20	33.5	67.5	18.2	4.4	6.5
Cisminskij 242	2.62	4.17	38.7	74.5	17.0	4.2	6.0
Dryden	2.55	4.57	40.2	77.0	16.0	3.2	8.0
Esa	2.42	4.10	35.2	64.2	16.0	3.4	8.5
Filby	2.42	4.02	7.2	35.7	16.0	2.7	6.5
Finale	3.37	4.40	36.0	67.0	14.7	3.1	7.0
Helka	2.52	3.62	30.0	62.0	15.2	3.5	7.5
Heikka	3.20	4.10	35.5	68.5	20.0	7.6	7.5
Hemmo	3.70	5.00	40.0	71.7	16.2	4.5	6.5
Tammi	2.90	4.27	36.5	71.2	21.0	5.5	6.5
Hja 51772	2.70	3.95	30.7	64.0	16.5	3.7	7.0
Hja 51775	2.45	3.77	28.2	59.2	15.7	3.2	7.0
Hja 51794	2.80	3.55	29.5	61.0	16.0	3.6	7.0
Hja 51821	2.40	3.72	31.7	63.7	16.0	3.1	7.0
Hja 51824	2.65	3.77	30.7	62.0	17.5	3.6	7.0
Hja 51846	2.42	4.25	35.7	66.5	17.7	5.0	8.5
Hja 51850	2.30	3.67	34.2	62.0	16.0	3.7	7.5
Hja 51862	2.52	4.25	36.7	69.5	19.7	6.9	7.0
Hja 51880	2.42	4.30	37.7	68.5	17.0	5.5	8.0
Hja 51891	2.62	4.02	30.0	62.2	17.7	3.5	7.5
Hja 51893	2.77	4.67	34.7	69.7	19.7	4.2	7.5
Hja 51902	2.47	4.32	31.7	65.2	20.0	4.6	6.5
Hja 52024	2.75	4.05	31.5	65.0	15.0	3.7	7.0
Hja 52076	2.22	3.90	35.7	72.5	16.2	3.1	8.0
Hja 52077	2.70	4.52	36.7	70.0	16.2	3.1	8.0
Hja 52096	2.57	4.17	36.7	73.5	15.7	3.2	6.5
Hja 52118	2.65	4.25	34.5	71.0	15.7	3.5	7.5
Hja 52206	2.62	3.47	30.7	62.5	13.2	3.4	5.5
Hja 52208	2.87	4.07	31.7	61.5	13.0	3.0	6.0
Hja 52257	2.50	4.27	38.2	66.5	15.5	4.1	9.0
Hja 52259	2.52	3.72	35.5	62.2	15.2	4.0	9.5
Jo 1068	3.47	5.60	37.5	75.5	21.0	7.1	7.0
Kimo	2.97	4.02	38.0	72.5	16.7	4.0	7.5
Osmo	2.52	3.82	33.7	68.5	16.0	4.1	7.5
Panu	2.52	4.12	30.2	64.0	16.2	3.2	7.0
Patu	2.70	3.62	29.2	63.5	18.5	3.7	6.5
Pika	2.70	4.25	32.5	66.0	15.2	4.6	5.5
Proco	2.97	3.95	29.5	60.7	13.0	4.2	6.5
Sv U 30321	3.00	3.97	29.7	64.7	17.5	4.2	6.5
Sv U 50004	2.45	4.02	31.7	62.0	21.2	3.5	7.0
Sv U 50021	2.32	3.80	30.0	66.5	18.5	3.5	7.5
F-values	41.6***	23.2***	116.2***	94.0***	118.2***	53.2***	—
$D_{5\%}$	0.73	1.11	6.91	9.10	2.63	2.80	—

When the measurements were made at the middle of the stem, the varieties Jo 1068, Hemmo and Hja 51893 had the thickest stems in the main trial. The last-mentioned was an afila-pea. In the preliminary trial, the varieties Hemmo, Hja 51893 and Hja 52194 had the thickest stems, the two last-mentioned being afila-peas. In the main trial varieties Hja 52206, Patu and Hja 51850, and in the preliminary trial Helka, Hja 51850 and Hja 52005 had the thinnest stems. All varieties with the thinnest stems were afila-peas. On the other hand, in the main trial the leafed varieties Proco, Heikka and Sv 30321 and Heikka and

Table 10. Morphological characteristics of 31 pea varieties. Preliminary trial Anttila 1985. Discarded varieties are omitted.

Variety	Diameter of stem		Dimensions of stipule		Number of nodes	No. of fertile nodes
	Base mm	Central part mm	Width mm	Length mm		
Heikka	2.45	3.55	29.0	57.2	17.7	6.4
Hemmo	3.22	4.57	35.0	67.7	15.2	3.9
Tammi	2.32	4.12	36.7	60.5	19.2	4.2
Hja 51663	2.45	3.67	30.2	61.0	15.7	3.2
Hja 51821	2.32	3.87	33.0	66.2	16.0	3.9
Hja 51828	2.42	3.95	30.7	60.5	17.5	3.2
Hja 51850	2.15	3.50	32.0	59.5	15.0	3.4
Hja 51879	2.67	4.10	35.2	66.7	14.0	2.7
Hja 51893	2.40	4.45	38.0	68.0	19.0	4.1
Hja 52005	2.17	3.57	30.2	61.5	13.7	3.9
Hja 52008	2.45	3.92	32.0	64.2	17.5	3.2
Hja 52020	2.17	3.62	29.7	56.2	14.7	2.4
Hja 52021	2.30	3.97	36.5	70.0	12.2	4.1
Hja 52024	2.30	3.85	31.7	63.5	14.5	3.1
Hja 52086	2.25	3.92	32.7	63.2	16.2	3.2
Hja 52092	2.25	4.00	33.7	65.5	15.2	2.7
Hja 52093	2.65	3.72	31.5	66.5	11.7	2.4
Hja 52104	2.42	4.12	38.2	69.7	14.5	2.5
Hja 52111	2.42	3.82	31.7	62.2	15.2	2.9
Hja 52118	2.27	3.97	33.5	64.0	15.2	2.7
Hja 52120	2.22	3.75	32.2	63.7	14.5	2.7
Hja 52128	2.35	3.95	34.0	68.0	15.2	2.7
Hja 52194	2.45	4.20	33.2	66.2	17.2	4.0
Hja 52208	2.62	4.12	33.5	66.2	12.5	2.7
Hja 52257	2.25	3.95	35.7	60.7	16.2	4.2
Hja 52259	2.12	3.87	36.7	60.5	15.5	3.7
Helka	2.15	3.45	28.5	58.2	15.2	3.6
Panu	2.30	3.95	31.5	64.0	14.2	3.2
Patu	2.32	3.60	27.7	56.7	17.0	3.4
Pika	2.17	3.57	28.7	57.5	13.0	3.5
Proco	2.77	3.47	29.0	58.5	11.7	3.1
Mean	2.31	3.85	32.47	62.38	15.6	3.43
F-value	6.17***	3.07***	5.44***	5.68***	15.16***	4.69***
$D_{5\%}$	0.53	0.88	7.28	9.84	2.47	1.63

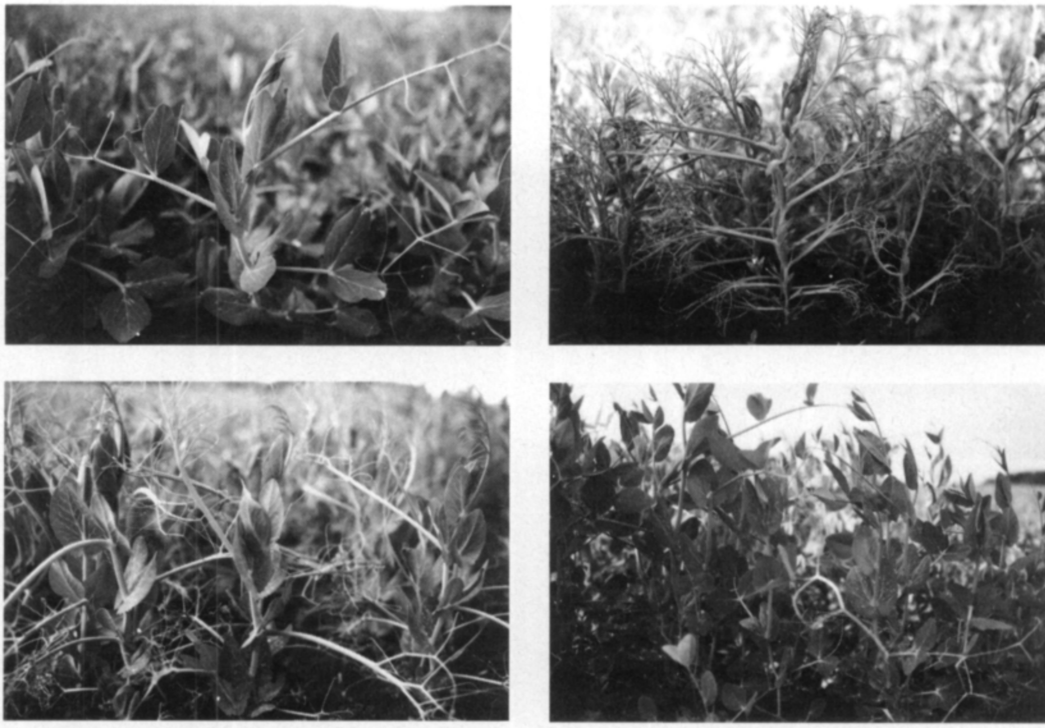
Proco in the preliminary trial had thinner stems than the grand mean. It can be concluded from the results that there are no genetical differences between the genotypes *afaf* and *AfAf* as regards the thickness of the central part of the stem. There were no fasciata-peas among the varieties tested.

When comparing the pure stand (main trial) with the mixed stand (preliminary trial), it can be concluded from the trial grand means that cultivation in mixed stands results in the stems being thinner both at the base and the central part of the stem. Bingefors et al. (1977) obtained a similar result.

Nitrogen application thickened the diameter of the stem base (Table 11), and also increased the thickness in the middle part of the stem. No interactions were found between the varieties and nitrogen application. Obviously a readily available supply of nitrogen enhances growth of the vegetative parts of the pea plants.

2.2. *Dimensions of the stipules*

The size of afila-pea stipules is considered to have an effect on the yield and lodging resistance (Snoad 1974, Hedley et al. 1983,



A C B D

Fig. 27. Pea varieties in early vegetative growth phase. Anttila 30. 6. 1985. A: Leafed varieties have a large LAI at an early stage and cover the soil surface well. Variety Allround. B: Afila-peas also grow quickly but the stand remains quite open. The stipules are already large and the tendrils strong. V. Helka. C: Peas with reduced stipules have a small LAI in the early growth phase. The LAI could be increased by using a higher plant density. V. Filby. D: Long-stemmed varieties often possess a high growth rate. V. Cisminskij 242.

Cousin et al. 1985, Pyke and Hedley 1985). In the main trial the varieties Dryden (*afaf*), Hemmo (*AfAf*) and Cisminskij 242 (*AfAf*) had the widest stipules (Table 9). In the preliminary trial the varieties Hja 52104, Hja 51893 and Tammi had the widest stipules (Table 10). Filby (*stst*) naturally had the narrowest stipules and also the shortest. The gene *af* does not have any effect on the width of the stipules. Genetically close varieties tended to have a similar stipule width. For instance, the sister genotypes Esa (Fig. 28 A), Hja 51880, Hja 52257 and Hja 52259 from the cross Filby/Garfield had wide stipules, and

Table 11. Morphological characteristics of peas at two nitrogen application levels.

	Diameter of stem		Dimensions of stipule		Number of nodes	No. of fertile nodes
	Base mm	Central part mm	Width mm	Length mm		
Average for 42 var.	2.71	4.11	33.2	65.9	16.8	4.08
Nitrogen 16	2.65	4.01	32.9	65.5	16.5	4.07
Nitrogen 80	2.77	4.22	33.4	66.4	17.1	4.09
F-values:						
nitrogen level	48.47***	28.27***	0.85	3.78***	5.57***	0.01
nitrogen x variety	0.97	0.78	0.03	2.24**	1.04	1.22

Fig. 28. Morphological characteristics of peas in the generative growth phase. Anttila 25. 7. 1985. A: Variety Esa has quite wide stipules. B: V. Helka possesses relatively narrow stipules. C: V. Proco typically bears two pods per node. The stipules are weakly marbled. D: V. Pika has short internodes and small pods. The stipules show distinct marbling. E: Pods of some afila-genotypes are concentrated at the top of the plant. V. Helka. F: The stipules of each variety are serrated in a typical fashion. V. Hemmo.

the genotypes Helka (Fig. 28 B), Hja 51772, Hja 51775 and Hja 51794 from the cross Proco/Hja 51221 had narrow stipules.

Dryden, Jo 1068 and Cisminskij 242 had the longest stipules. These, as well as Hemmo, may have the largest stipule area. In the preliminary trial the lines Hja 52021, Hja 52104 and Hja 51893 had the longest and largest stipules. Helka and its sister lines had short stipules with a small surface area. In the preliminary trial the varieties Helka, Hja 52020, Helka, Patu, Pika and Proco had short stipules with a small surface area. Stipule characteristics are often important for variety identification (Fig. 28 A-D, F).

Although the differences between the varieties as regards the dimensions of the stipules were distinct, transgression for a smaller size would possibly be advantageous, at least for cultivation systems where the density of the stand is high. It may not be possible to find a generally accepted optimum size owing to other varietal characteristics and variable growing conditions. Stipule size must have an effect on the pod filling rate, because seeds derive a large proportion of their carbon from photosynthesis in the leaflets and stipules at the parent node (PATE 1975). Numerous experiments have been carried out to determine optimum stipule size (PYKE and HEDLEY 1985, SNOAD 1985). Judging by MAHON's (1982) results, it might be possible to obtain a higher LAI (Leaf Area Index) through larger stipules, while at the same time a lower CER (CO_2 exchance ratio). Variability in stipule size causes differences in growth rate while the plants are still small.

Nitrogen application did not have any effect on the width of the stipules, but increased the length of the stipules and probably also their area (Table 11). There were interactions between nitrogen application and the varieties as regards stipule length.

2.3. Number of nodes

The number of fertile nodes is a yield component and internode length is associated with the susceptibility to lodging (GOTTSHALK and HUSSEIN 1975, FLENGMARK 1984, STOY 1984).

The late varieties Sv U 50004, Tammi (Fig. 29 D) and Jo 1068 had the greatest total number of nodes, viz. 21, on their stems (Table 9). In the preliminary trial Tammi and Heikka possessed the greatest number of nodes (Table 10). MAKASHEVA (1983) mentioned that late varieties usually have 16—21 "nonbearing" nodes. In comparison to this, varieties classified as late in northern conditions have the smallest total number of nodes. Of the varieties tested, the number of nodes on the extremely early varieties Hja 52208, Proco and Hja 52206 totalled only 13. In the preliminary trial, too, the early varieties Hja 52093, Proco, Hja 52021 and Hja 52208 had the smallest number of nodes, viz. 12. The results are in agreement with the finding of MAKASHEVA (1983), that early varieties have 7—11 "nonbearing" nodes. The total number of nodes seems to agree well with the growing time of a variety. Certain types of variety, such as Heikka and Hja 51893, were exceptions since they had a relatively large number of nodes in spite of medium earliness. Node number and length indicates much about plant architecture as a varietal character (Fig. 29).

In the main trial the varieties had, on the average, 4 fertile or pod-bearing nodes. The leafed varieties Heikka and Jo 1068 had the greatest number of fertile nodes. A high number of fertile nodes is inherited from Heikka; its offspring lines Hja 51862 and Hja 51846 from the cross Filby/Heikka also had a large number of fertile nodes. These lines are afila-peas. In the preliminary trial Heikka had again the highest number of nodes, followed by the afila-varieties Tammi and Hja 52257. In the light of these results it would appear that the afila-character does not have an effect on the number of fertile nodes. In the main trial Filby had the smallest number of fertile nodes, only 2.7. Many other early varieties, like Hja 52206, Hja 52208 and Panu, had only a few pod-bearing nodes. Obviously this yield component could be partly compensated by other factors, because many high yielding varieties like Esa, Helka and Patu had a smaller number of fertile nodes than the average. YOUNG and RUSHBROOK (1983) considered the number of pod-bearing nodes an important yield component. STOY (1984) proposed that a suitable number is 4—6 nodes. A greater number would cause too great a maturity difference between the seeds, too small a number would cause premature termination of growth.

Nitrogen application significantly increased the total number of nodes (Table 11). This is connected with the general effect of nitrogen, which increases vegetative growth. There was no interaction between variety and nitrogen application. Nitrogen application did not increase the number of fertile nodes.

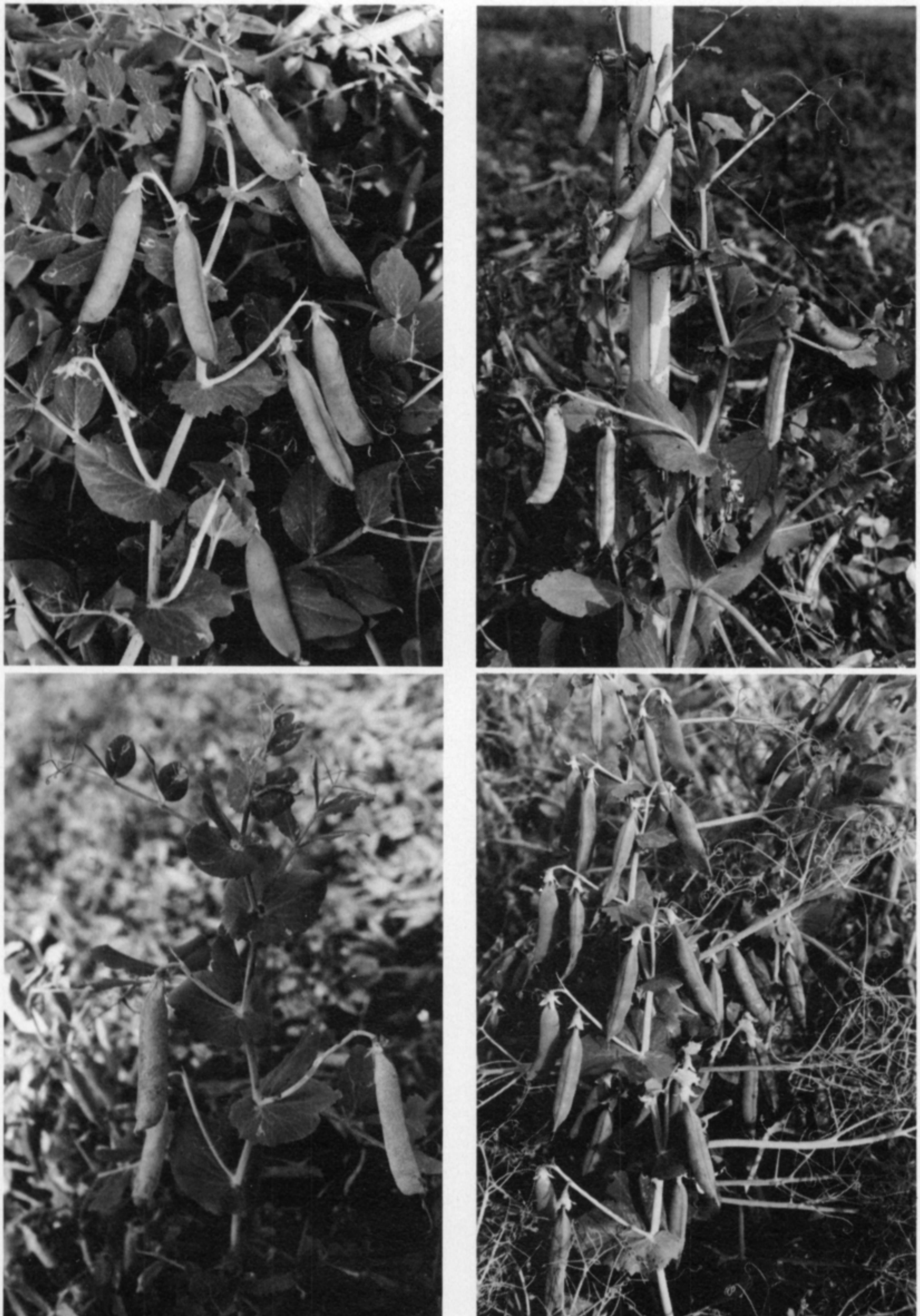


Fig. 29. Pea plants with different architecture. Anttila 17. 8. 1985. A: Variety Hemmo; semi-high stemmed of conventional leaf type. B: V. Proco; early and leafed, possessing short internodes. C: V. Heikka; semi-high stemmed and leafed with thin, curved pods. D: V. Tammi; typical late afila-pea showing large number of

nodes. E: V. Filby; leafless with reduced stipules. F: V. Hja 51824; semi-high stemmed afila-pea. G: V. Pika; low-stemmed afila-pea with small plant size. H: V. Panu; afila-pea with pods remaining green close to ripening time. I: V. Esa; semi-high stemmed afila-pea with short internodes and large stipules. J: V.

Osmo; semi-high stemmed afila-pea possessing small stipules and thin pods. K: V. Hja 51850; semi-high stemmed and early, with small stipules and thin pods. L: V. Hja 52208; extremely early afila-pea showing weak vegetative growth.

2.4. *Number of seeds per pod*

The results are based on observations from only two plants per line (Table 9, Fig. 30). The varieties Esa (Fig. 30 D), Hja 52257 and Hja 52259 had the most, on the average 9 seeds per pod. These afila-varieties originate from the cross Filby/Garfield. They possess a relatively small seed size, but high yielding ability. This refers to the advantage of enlargened pod volume with increased photosynthetic capacity in relation to seed size (Pate 1985). The extremely early varieties Hja 52206 and Pika (Fig. 30 C) had only 5.5 seeds per pod. The distinctly large-seeded varieties like Allround, Cisminskij 242 and Finale (Fig. 30 B) also had a relatively low seed number. Makasheva (1983) regarded a seed number of 7—12 as high, and a maximum number when source material for breeding are being selected. One must also take into consideration the result obtained by Lamprecht (1946, 1947), in which three-flowered inflorescences form pods carrying a smaller number of seeds than two-flowered ones. Some of the ovules die, and the rest develop into seeds. The proportion is partly determined by heredity (Hardwick 1985). In order to minimise energy use, a good variety is a type which has a very low death rate of ovules even in stress situations. Under Finnish growing conditions, pods of small-seeded varieties generally seem to be full without abortions. A small seed size should be combined with a large pod that remains green for as long as possible in order to render carbon assimilation more effective (Flinn 1985, Price and Hayward 1986), see also Fig. 29 H.

2.5. *Relationships between agronomic and morphological characteristics*

Phenotypic correlation coefficients for the pure stand (main trial) are set out in Table 12,

Fig. 30. Seeds in the pods of some varieties at the end of the podfilling stage. Anttila 17. 8. 1985. A: Small seeds of v. Heikka are tightly packed in pod. B: Large seeds of v. Finale. C: Short pod with a low number of

seeds of v. Pika. D: V. Esa has a large number of tightly packed seeds. E: Seeds of v. Panu remain green close to maturity. F: Typical seed number for v. Helka.

Table 12. Phenotypic correlations between varietal agronomic and morphological characteristics. Main trial 1985.

Characteristic	Seed yield	Lodging	Growing time	Stem height	Leaf type	Stem base diameter	Stem central diameter
Lodging	—0.04						
Growing time	—0.32*	—0.25					
Stem height	—0.02	0.12	0.30				
Leaf type	0.29	—0.68***	—0.13	—0.04			
Stem base diam.	—0.29	0.39*	0.16	—0.12	—0.74***		
Stem central diam.	—0.24	0.23	0.29	0.31*	—0.40**	0.56***	
Stipule width	0.07	0.24	0.23	0.35*	—0.45**	0.25	0.42**
Stipule length	0.13	0.32*	0.20	0.49***	—0.45**	0.27	0.48**
No. of nodes	—0.11	—0.16	0.68***	0.52***	—0.04	0.05	0.34*
No. fertile nodes	—0.16	0.09	0.37*	0.24	—0.43**	0.38*	0.45**
No. seeds/pod	0.31*	—0.05	0.16	—0.06	0.22	—0.36*	—0.07
Harvest index	0.51***	0.24	—0.51***	—0.50***	0.04	—0.18	—0.20
1000-sw.	—0.19	0.26	—0.21	—0.09	—0.28	0.39**	0.20

Characteristic	Stipule width	Stipule length	No. of nodes	No. of fertile nodes	No. of seeds/pod	Harvest index
Stipule length	0.92***					
No. of nodes	0.13	0.24				
No. fertile nodes	0.36**	0.36*	0.58***			
No. seeds/pod	0.29	0.12	0.06	—0.03		
Harvest index	—0.09	—0.11	—0.56***	—0.30	0.22	
1000-sw.	0.10	0.16	—0.39**	—0.42*	—0.43**	0.08

and for the mixed stand (preliminary trial) in Table 13. Under the climatic conditions prevailing in 1985, the pure stand yield correlated negatively with growing time, but positively with the seed number per pod and highly significantly with harvest index (HI). Other

Table 13. Phenotypic correlations between varietal agronomic and morphological characteristics. Preliminary trial 1985.

Characteristic	Seed yield	Lodging	Growing time	Stem height	Leaf type	1000-sw.
Lodging	—0.05					
Growing time	—0.12	0.07				
Stem height	0.39**	0.61***	0.17			
Leaf type	0.41**	—0.42**	0.05	—0.06		
1000-sw.	0.41**	—0.37*	—0.14	—0.08	0.45	
Stem base diam.	0.08	—0.15	0.08	—0.12	—0.12	0.64***
Stem central diam.	0.18	0.08	0.26	0.25	0.27	0.50***
Stipule width	0.21	—0.05	0.20	0.11	0.46***	0.44***
Stipule length	0.36**	—0.03	—0.17	0.09	0.36**	0.69***
No. of nodes	—0.09	0.43**	0.64***	0.40**	0.06	—0.36**
No. fertile nodes	—0.32*	—0.09	0.51***	—0.01	—0.25	—0.39**

Characteristic	Stem base diameter	Stem central diameter	Stipule width	Stipule length	No. of nodes
Stem central diam.	0.56***				
Stipule width	0.40**	0.77***			
Stipule length	0.52***	0.70***	0.74***		
No. of nodes	—0.27	0.16	0.02	—0.24	
No. of fertile nodes	0.01	0.10	0.01	—0.20	0.27

morphological characteristics correlated weakly with yield. A model for the hectare yield was calculated by multiple regression analysis (characteristics from Table 12, stepwise, F-value < 4.0 removed):

$$Y = 4199—695X_1 + 28.6X_2 + 173X_3$$

where X_1 = stem base diameter, mm, X_2 = stipule length, mm and X_3 = HI, %. Together they explained only 37 per cent of the yield, $R^2 = 0.37$.

In the mixed cropping trial total yield correlated positively with stem height, leaf type, seed size and stipule length of pea respectively. Surprisingly the correlation between total yield and the number of fertile nodes was negative. A model of total hectare yield was calculated by multiple regression analysis (characteristics from the Table 13, stepwise, F-value < 4.0 removed):

$$Y = 654 + 27.3X_1 + 483X_2 + 4.32X_3$$

where X_1 = stem height of pea, cm, X_2 = leaf type and X_3 = thousand seed weight of pea, g. This model explained only 38 per cent of the total yield ($R^2 = 0.38$). It is easily understandable that the stem height of pea was of importance as a yield factor, because there was competition between peas and the supporting cereal in the trial. A large seed size may also benefit competition ability. Manifestation of leaf type as a yield factor is of fundamental importance; the afila-genotype formed higher yielding stands with cereals than the leafed varieties. It is notable that the characteristics stem thickness, stipule dimensions and node number were of no importance for total yield. Judging by the relatively low R^2 values, none of the characteristics dealt with was a decisive selection criterion for yield as such. However, inclusion of characteristics like HI in the models deserves consideration in selection work.

In the pure stand, lodging correlated negatively with leaf type but positively with stem base thickness and stipule length. In the mixed stand it correlated positively with stem height and node number of peas, but negatively with leaf type and seed size. A regression model was calculated from the pure stand in order to determine lodging per cent (characteristics from Table 12, stepwise, F-value < 4.0 removed):

$$Y = 199.3—1.15X_1—25.6X_2$$

where X_1 = growing time d, X_2 = leaf type. R^2 was 0.55. Another regression model was calculated from the respective mixed crop trial (Table 13):

$$Y = 2.8 + 1.15X_1—34.7X_2 + 4.64X_3—10.4X_4$$

where X_1 = pea stem height, X_2 = leaf type, X_3 = no. of nodes, and X_4 = no. of fertile nodes. R^2 was 0.62. The most strongly explaining factor in both models was leaf type; in practice the difference between the normal leaf type and afila-type. Growing time, height and number of nodes, all positively correlated, had increasing effects on lodging. It should be noticed that stem thickness and dimensions of the stipules were not important enough to warrant their inclusion in the models.

In pure stand cultivation the positive correlation between stem thickness, both at the base and middle part of the stem, and lodging was surprising. The reason for this relationship is hidden in the negative correlation between leaf type and stem thickness. The genotype *afaf* had a thin stem base, but despite this they had better lodging resistance than the leafed varieties with a thicker stem base. The following model was calculated for lodging per cent when only the afila-peas were included in the multiple regression (characteristics from the Table 12):

$$Y = 106.1—1.55X_1 + 0.678X_2 + 5.26X_3$$

where X_1 = growing time d, X_2 = stem height cm, X_3 = no. of seeds per pod. R^2 was 0.48. In this case, too, stem thickness and stipule dimensions were not included in the model.

In addition, some other interesting correlation coefficients are to be found in tables. For instance, the positive correlation between stipule dimensions and the diameter of the middle part of the stem. As HEDLEY et al. (1983) stated, the assimilating capacity of the stipules may be of importance for stem growth. The strong positive correlation between stipule length and width means that, within the genotype *afaf*, only one of the dimensions needs to be measured. The negative correlation between HI and characteristics like growing time, stem height and number of nodes indicated that longstemmed, late varieties are poorly adapted to Finnish growing conditions. Seed size was positively correlated with stem base thickness, but negatively with node numbers, fertile nodes and number of seeds per god. The last mentioned may be connected with seed abortion, and the decrease in yield caused by too large a seed size (HARDWICK 1985).

2.6. *Harvest index*

Large varietal differences were found in the harvest indices (HI), calculated as an average of two years (Table 14). The short and leafed varieties Allround, Proco and Sv U 030321 had the highest HI. The late, semi-high stemmed afila-peas Sv U 50004 and Tammi had the lowest HI. The majority of the varieties had a HI near the mean of 54.9 per cent. This is a higher value than the one presented by STOY (1984). It is worth noting that a high HI was reached irrespective of the fairly high seeding rate of 120 seeds/m^2 (Filby 140). Seeding rates of over 100 seeds have been shown to decrease HI (PYKE and HEDLEY 1985). Old Finnish varieties had a HI of 16—45 per cent only (PESOLA 1935). The simultaneous increase in yield and HI may be connected with the statement made by MAHON (1982), that lines selected according to high CER (CO_2 exchange rate) usually have a high HI.

Nitrogen application had a contradictory effect on HI (Table 15). It tended to lower the HI in 1984, but in 1985 it increased the HI significantly. The difference between the years indicates the dependence of nitrogen application on climatic conditions. There was no interaction between varieties and the nitrogen

Table 14. Harvest index percentage of 31 pea varieties. Main trials 1984—85.

Variety	Harvest index percentage
Allround	60.7
Barcota	54.5
Esa	58.7
Filby	52.1
Finale	54.5
Heikka	52.8
Hemmo	54.2
Tammi	47.7
Hja 51772	54.4
Hja 51794	56.3
Hja 51824	53.7
Hja 51846	57.3
Hja 51850	56.3
Hja 51862	50.7
Hja 51880	56.1
Hja 51893	54.7
Hja 51902	55.0
Hja 52076	54.0
Hja 52077	55.7
Hja 52096	53.8
Hja 52206	57.0
Helka	50.4
Jo 1068	54.4
Kimo	58.5
Osmo	52.8
Panu	57.6
Pika	56.3
Proco	59.4
Sv U 30321	59.4
Sv U 50004	42.2
Sv U 50021	54.5
Mean	54.9
F-value, arcsin	3.72***
$D_{5\%}$	2.74

Table 15. Harvest index at two nitrogen application levels. Mean of 42 varieties.

	Harvest index percentage	
	1984	1985
Nitrogen 16	54.3	57.0
Nitrogen 80	52.1	57.6
Mean	53.2	57.3
F-value (arcsin)		
N-levels	1.45	20.22***
N x variety	0.77	0.79

Correlation between varietal results in 1984 and 1985 and regression (arcsin) r = 0.58***, y = 26.19 + 0.49x.

levels, as has been found in wheat (RUCKENBAUER 1984). The HI of varieties in the years 1984 and 1985 was significantly correlated (r = 0.58***, r^2 = 0.336), which reflects a high heritability. Thus selection for HI would be efficient provided it can be done under stand density conditions. The environment used for the selection was the density given by the seeding rate of 120 seeds/m^2. The ranking of the HI of the varieties might be different with other densities. Indicating the differences in the behaviour of genotypes within a stand, HEDLEY and AMBROSE (1984, 1985) considered HI to be a poor selection criteria. Vigorous varieties often exhibit a low HI (HEATH and HEBBLETHWAITE 1985).

The harvest indices presented in the results are higher than those proposed for any cereal (KERTESZ 1984). The HI must be studied with respect to other characteristics of a variety, e.g. stem height. For instance, the short-stemmed varieties Allround and Proco possess very high HI, but only a medium yield level. A HI of 60 per cent may possibly be a realistic upper limit. This limit has almost been reached in cereals (APEL 1984). The diverging energy values of different plant organs have not been taken into consideration in the produced results (SING and SWAMINATHAN 1984), and comparisons of harvest indices would have to be adjusted if they were taken into account.

Table 16. Lodging of 30 pea varieties in the generative growth phase. Main trials 1984—85.

Variety	Lodging percentage in three phases		
	End of flowering	End of pod filling	Full maturity
Allround	6	62	90
Barcota	1	27	73
Esa	1	31	72
Filby	0	5	50
Finale	3	44	81
Heikka	21	47	68
Hemmo	4	53	73
Tammi	0	9	59
Hja 51772	0	43	73
Hja 51794	2	45	73
Hja 51824	1	29	67
Hja 51846	1	38	76
Hja 51850	0	30	64
Hja 51880	0	36	76
Hja 51893	2	39	85
Hja 51902	2	30	67
Hja 52076	8	38	62
Hja 52077	9	40	67
Hja 52096	12	49	85
Hja 52206	0	31	53
Helka	0	30	67
Jo 1068	25	40	64
Kimo	0	21	67
Osmo	0	32	73
Panu	0	35	66
Pika	0	18	42
Proco	22	70	83
Sv U 30321	16	46	88
Sv U 50004	0	5	54
Sv U 50021	0	28	62
Mean	5	34	68
F-value (arcsin)	1.18	4.37***	3.35***
$D_{5\%}$	—	26.2	16.8

2.7. *Lodging during the generative phase*

2.7.1. Lodging of 30 pea varieties

The stands of many of the leafed varieties were already lodged at the end of the flowering period (in Table 16 e.g. Allround, Heikka, Proco). Most of the afila-peas such as Helka, Kimo and Osmo were still fully standing. However, no variety had lodged badly in this early stage.

During seed fill the pea stand becomes heavier and heavier, and may lodge if there is excessive rain. Sudden lodging may also take place as a result of drought stress. It is often difficult to make objective observations of lodging resistance on the experimental field because varieties with a different growth rhythm are not at the same stage of lodging susceptibility when it rains. Thus several observations of lodging are needed. Varietal differences in lodging are most pronounced just before the process of ripening. According to the results obtained in this study, the varieties Allround, Hemmo and Proco were most seriously lodged at the seed-fill stage. The varieties Filby (*afaf. stst*), Sv U 50004 (*afaf*) and Tammi (*afaf*) were still mostly standing. Significant differences in lodging were also found between the afila-breeding lines (Hja-lines, Sv-lines) and the afila-varieties Barcota, Esa, Helka, Kimo, Osmo, Panu and Pika at this stage. JOHANSSON (1984) also pointed out lodging differences between afila-varieties.

The varietal differences decreased relatively when lodging was observed at full maturity, because at least half of the stands of the genotypes *afaf* had also lodged. The experiments show that Pika and Filby had the best standing ability, and Allround the poorest. The significant differences between the varieties provide a good basis for selection. Considering only the lodging resistance, the "Filby-type" looks promising under Finnish conditions, as is the case in England (SNOAD 1974, 1985, HEDLEY et al. 1983).

2.7.2. Correlation between yield and lodging

The lodging of stands at the end of flowering was an obvious disadvantage in 1984, because the correlation between lodging and yield was significantly negative (Table 17). In 1985 lodging was less pronounced owing to less precipitation in July. There was no relationship between lodging during the seed-fill stage and yield in either of the years.

A significant negative correlation was found between lodging of the ripened crop and yield in 1984, but not in 1985. The lodged varieties were harvested with heavy losses in 1984, which may partly explain the result. Correspondingly KIELPINSKI and BLIXT (1982) pointed out the small realized yield of conventional leafed varieties by comparing their yield potential. Lodging was clearly the most important reason for this. Varieties which are inclined to lodge are apparently not capable of producing a high yield in conditions that favour high yield levels, like in 1984.

Table 17. Correlation between seed yield and lodging (arcsin). Main trials 1984—85. 42 varieties.

Growth phase	Correlation coefficient, r	
	1984	1985
End of flowering	—0.30*	0.05
End of pod filling	—0.02	0.14
Full maturity	—0.32*	0.12

Regression of yield on lodging in 1984 in phases:
End of flowering y = 4724 + (—27.1x)
Full maturity y = 7254 + (—49.1x)
Seed yield mean 1984 4608 kg/ha, 1985 4242 kg/ha.

2.7.3. Lodging of normal leafed vs. afila-peas

The afila-varieties lodged significantly less than the leafed varieties throughout the whole of the generative growth phase in both 1984 and 1985 (Table 18). The effect of the gene *af* in improving lodging resistance was unquestionable. This, or at least the fact that lodging is postponed to the last weeks of the growing period, has been verified in many investigations (SNOAD 1974, GOTTSCHALK 1980, KIELPINSKI and BLIXT 1982, MAKASHEVA 1983). However, no afila-variety was found to have fully escaped lodging at the time of combining. On the average, two thirds of their stands were lodged at the time of ripening in 1984—85. The afila-character is not the sole solution to the lodging problem (HEATH and HEBBLETHWAITE 1984). The afila-character

Table 18. Lodging of normal leafed vs. afila pea varieties. Main trials 1984—85. 42 varieties. t-tests with arcsin transformation.

Year	Growth phase	Normal leafed		Afila-peas		t-value
		n	Lodging-%	n	Lodging-%	
1984		13		29		
	End of flowering		6		0	5.71***
	End of pod filling		50		19	7.53***
	Full maturity		74		61	5.81***
1985		5		37		
	End of flowering		32		2	5.28***
	End of pod filling		54		41	2.21*
	Full maturity		82		71	2.32*

has to be combined, e.g. with the fasciata-genotype (GELIN 1956) or with an exceptional stem rigidity and lignification (ESKILSSON 1962, BINGEFORS et al. 1979 a, MAKASHEVA 1983). Long term "variety evolution" should be developed in this direction so that the pea crop would become more selfsupporting, as has been the case inside *Phaseolus* (SMARTT 1976). With this object in view, variability could be widened by crosses between species or by gene transfers (COMB 1975).

2.8. *Root and shoot characteristics and nodulation*

2.8.1. Root properties at two nitrogen levels

The effect of nitrogen application on the dry weight of pea roots remained insignificant (Table 19). Significant differences between varieties have been found each year as regards root dry weight. However, due to the sampling technique, part of the roots of deep-rooted varieties were not removed with the samples. The main root may reach a depth of 1.0—1.5 m (MAKASHEVA 1983). Interactions between nitrogen application and variety were weak (see F-statistics, Table 19).

The higher level of fertilizer impaired nodulation. The nitrogen application consisted of equal parts of nitrate and ammonium nitrogen. According to many investigations, nitrogen application weakens nodulation (RAININKO 1968, JACOBSEN and NIJDAM 1983, MAKASHEVA 1983). Differences were observed between the nodulation rate of the different varieties. The interactions between the nodulation rate of a variety and nitrogen application level were statistically significant in 1979 and 1981. Varietal differences in nodulation capacity have been well documented (GELIN and BLIXT 1964, JACOBSEN and HENNINGSEN 1980, COUSIN et al. 1985, JENSEN 1986 a).

Table 19. Root characteristics of peas at two nitrogen application levels. Main trials 1979—82.

Year		Dry matter g	Nodulation score 1—3	Crude protein %	Crude protein mg
1979	16 N	0.19	2.81	18.0	35
N = 25	80 N	0.17	1.86	13.9	24
	Mean	0.18	2.30	15.9	30
	F nitrogen appl.	1.00	62.67***	38.82***	2.98
	F varieties	3.00***	2.58**	1.76*	3.41***
	F nitr. x var.	1.11	2.05*	0.78	1.23
1980	16 N	0.11	2.30	14.8	17
N = 25	80 N	0.13	2.00	14.4	18
	Mean	0.12	2.15	14.6	18
	F nitrogen appl.	0.62	0.28	0.05	0.05
	F varieties	9.34***	2.22**	3.44***	7.27***
	F nitr. x var.	1.08	0.96	1.56	1.45
1981	16 N	0.16	2.50	25.2	40
N = 25	80 N	0.15	1.84	21.8	33
	Mean	0.16	2.17	23.5	37
	F nitrogen appl.	1.42	0.45	10.60**	5.35*
	F varieties	3.37***	3.61***	3.46***	4.83***
	F nitr. x var.	0.59	2.02*	1.02	0.84
1982	16 N	0.24	2.95	21.8	53
N = 10	80 N	0.23	1.35	18.2	39
	Mean	0.24	2.15	20.0	46
	F nitrogen appl.	0.09	28.40***	25.59***	15.14**
	F varieties	10.45***	0.44	2.26	12.46***
	F nitr. x var.	0.55	0.67	2.57	1.45

The protein content of nodulated roots was lower with the high nitrogen application level in three years out of four. This may be as a result of inadequate nodulation. Varietal differences were also found in the protein content of the roots. No interactions were found between the preceding factors.

High nitrogen application decreased the amount of total protein in the roots in two years out of four, due to a fall in the protein content. Varietal differences in protein quantity were large. There were no interactions between variety and nitrogen application level. Additional work would be needed to clarify what sort of physiological effects could the decreased nitrogen quantity of roots have on growth during the vegetative growth phase (JENSEN 1986 b).

2.8.2. Shoot properties at two nitrogen levels

High nitrogen application increased shoot weight significantly in 1979 and 1980 (Table 20). Farmers often find that a pea crop fertilized with nitrogen has a luxuriant growth, this being the reason why nitrogen application is frequently used. There were noticeable differences in shoot weight between the varieties. The varieties used in the trials were both short and long stemmed. No interactions occurred between nitrogen application level and variety.

In two years out of four the high level of nitrogen application lowered the protein content of the shoots. Varietal differences were observed each year. No interactions were found between these factors.

The higher amount of applied nitrogen significantly increased the amount of protein in the shoots in one year only. Differences between the varieties were noticeable in three years, but there were no interactions between either factors.

2.8.3. Root and shoot characteristics of leafed vs. afila-peas

The afila-peas generally had a smaller root weight than the leafed varieties (Table 21). They also had a smaller number of root nodules. All the varieties used in the experiments were white flowered which, according to JENSEN (1986), have an inferior nodulation ability. Some of the afila-varieties, however, nodulated fairly well.

The roots of the afila-varieties had a lower protein content than the leafed varieties which, in addition to a smaller root size, resulted in a low protein amount. Although the number of afila-varieties included in the study was small, the results from different years were similar. The different nitrogen metabolism of afila-peas may arise from interaction between *Pisum* and *Rhizobium* (HOBBS and MAHON 1983, LJUNGGREN 1984), or differences in the nitrate reduction capacity of the root and the shoot systems (JENSEN 1986 b).

The amount of shoot dry matter in both leaf types proved to be similar (Table 22). Similarly, HEDLEY et al. (1983) found that the afila-genotype and leafed peas possess the same growth rate during the vegetative phase. In one of the years the leafed varieties had a significantly higher protein content than the afila-peas. The situation was similar in the roots of the same samples (Table 21). Considering all the trial years together, there were no differences between the protein quantity of the shoots of the afila-peas and the leafed varieties.

To summarize, it can be concluded that the gene *af* has strong effects on the nitrogen metabolism of the roots, but not of the shoots.

2.8.4. Relationships between root and shoot characteristics and seed yield

Protein yield was determined almost totally by the seed yield, and correlations of both with other characteristics were almost similar (Table 23). Negative correlations between yield and characteristics such as root dry matter, root protein amount, shoot dry matter and amount of shoot protein are difficult to interpret. Reliable conclusions cannot be drawn since there was only one sampling time. The most likely cause of the foregoing result

Table 20. Shoot characteristics of peas at two nitrogen application levels. Main trials 1979—82.

Year		Dry matter g	Crude protein %	Crude protein g
1979	16 N	3.0	20.5	0.61
N = 25	80 N	4.3	20.3	0.88
	Mean	3.7	20.4	0.75
	F nitrogen appl.	4.15*	0.02	2.30
	F varieties	2.07*	2.96*	1.61
	F nitr. x var.	0.90	1.39	0.81
1980	16 N	2.9	17.3	0.50
N = 25	80 N	3.2	17.8	0.57
	Mean	3.1	17.5	0.54
	F nitrogen appl.	4.39*	1.63	72.12***
	F varieties	2.27**	3.54***	2.28**
	F nitr. x var.	1.14	0.85	0.96
1981	16 N	3.0	23.1	0.68
N = 25	80 N	3.4	22.1	0.74
	Mean	3.2	22.6	0.71
	F nitrogen appl.	0.50	5.67*	0.25
	F varieties	2.06*	10.39***	2.36**
	F nitr. x var.	0.94	1.07	1.08
1982	16 N	4.2	18.4	0.76
N = 10	80 N	5.0	16.7	0.83
	Mean	4.6	17.5	0.80
	F nitrogen appl.	1.00	13.38**	0.15
	F varieties	5.23**	2.65*	2.50*
	F nitr. x var.	0.29	1.28	0.14

was that the roots and shoots of late and long-stemmed varieties contained fairly large amounts of nitrogenous compounds at the time of sampling. Varieties of this kind are not able, however, to express their yield capacity under Finnish growing conditions, but achieve a lower yield level than varieties with earlier maturity. In contrast to what has been presented earlier (SINCLAIR and DE WIT 1975), nitrogen storage by vegetative plant organs or

Table 21. Root characteristics of leafed vs. afila peas. Main trials 1979—82.

Year		n	Dry matter g	Nodulation score 1—3	Crude protein %	Crude protein mg
1979	Leafed	20	0.19	2.46	16.05	31.15
	Afila	4	0.15	2.07	15.32	24.20
	t		1.20	2.14*	1.06	1.36
1980	Leafed	20	0.12	2.30	14.73	18.65
	Afila	4	0.10	1.81	14.22	14.75
	t		1.32	2.46*	0.19	1.69
1981	Leafed	15	0.16	2.26	24.15	42.64
	Afila	9	0.13	2.09	22.74	30.70
	t		1.33	1.03	2.40*	5.42*
1982	Leafed	5	0.28	2.20	19.96	55.20
	Afila	4	0.21	2.12	18.40	39.50
	t		2.54*	0.88	3.08*	2.66*

the transfer of nitrogen from these sites to growing seeds appear to have no importance for the protein yield.

Four characteristics, the amount of dry matter and protein in the roots and the amount of dry matter and protein in the shoots, were correlated significantly and positively *inter se*. No correlation was found between the nodulation rate and yield. The high number of nodules is evidently of no benefit to the yield, if the other properties like growing time of a variety are not at the optimum. Positive correlation was found between the nodulation rate and the amounts of both dry matter and protein in the roots. JENSEN (1986) pointed out the same.

Table 22. Shoot characteristics of leafed vs. afila peas. Main trials 1979—82.

Year		Dry matter g	Crude protein %	Crude protein g
1979	Leafed	3.75	20.35	0.75
	Afila	3.55	21.10	0.73
	t	0.44	0.72	0.23
1980	Leafed	3.10	17.31	0.53
	Afila	3.15	18.22	0.57
	t	0.15	1.09	0.63
1981	Leafed	3.15	24.10	0.69
	Afila	3.26	20.86	0.74
	t	0.08	5.05**	1.17
1982	Leafed	4.70	17.90	0.83
	Afila	4.85	16.90	0.81
	t	0.44	1.20	0.31

2.8.5. Root and shoot characteristics of six varieties

Hemmo had the highest amount of root dry matter and Filby the smallest (Table 24). It is also noteworthy that the afila-variety Tammi had a small root system in spite of its lateness. The long-stemmed variety Hertta did not have a stronger root system than the relatively

Table 23. Phenotypic correlations between yield, nitrogen application and root and shoot characteristics. Main trials 1979—80, —82. 120 observations.

Characteristic	Seed yield	Protein yield	Nitrogen applic.	Root dry matter	Shoot dry matter	Root prot. quantity	Shoot prot. quantity
Protein yield	0.97**						
Nitrogen applic.	0.01	0.02					
Root dry matter	—0.25**	—0.28**	—0.04				
Shoot dry matter	—0.15	—0.15	0.37**	0.60**			
Root prot. quantity	—0.22*	—0.26**	—0.22*	0.91**	0.43**		
Shoot prot. quantity	—0.19*	—0.19*	0.35**	0.61**	0.91**	0.45**	
Nodulation score	—0.05	—0.05	—0.59**	0.22*	—0.16	0.32**	—0.10

Table 24. Root and shoot characteristics of six pea varieties. Main trials 1979—82.

Variety	Root				Shoot		
	Dry matter g	Nodulation score 1—3	Crude protein %	Protein mg	Dry matter g	Crude protein %	Protein g
Filby	0.10	1.82	17.3	17	2.7	19.2	0.51
Heikka	0.16	2.37	18.8	30	3.3	19.6	0.65
Hemmo	0.21	2.45	18.4	40	3.7	20.2	0.74
Tammi	0.15	1.96	18.5	28	3.4	20.5	0.68
Hertta	0.19	2.30	19.3	38	4.1	18.6	0.75
Proco	0.18	2.31	18.1	35	3.5	19.2	0.65
F varieties	4.43*	3.53*	1.52	4.76**	3.18*	0.72	2.76
LSD	0.09	0.61	—	17	1.2	—	—

short-stemmed Hemmo. Both are late varieties. Ranking of the varieties according to the size of the root system and the nodulation rate was almost the same, obviously due to the dependence of the nodulation rate on the former characteristic.

There were no significant differences between the varieties as regards the protein content of the roots. Owing to its small root system, Filby had a lower protein quantity in the roots than the other varieties.

The long-stemmed variety Hertta had a significantly larger shoot dry mass than Filby. The other varieties were placed between them. The differences between the shoot protein content of the varieties were very small. Filby had the smallest shoot protein quantity.

In summary, lateness and stem height are not necessarily linked to the size of the root system or its protein amount. Instead lateness and height are positively connected with size and protein amount of the shoot system. The small root system of the genotypes *afaf. StSt* and *afaf. stst,* particularly, may prove to be a disadvantageous character in stress situations. Small roots may be related to the slow growth rate of *stst*-genotypes (HEDLEY et al. 1983).

3. Variation and selection of protein content — importance of breeding for high protein content

3.1. *Effect of genotype on the protein content in consecutive years*

When one considers the results of the variety trials it is clearly evident that varieties have characteristic protein contents. The protein content of the varieties in 1982—86 was based on the average from 4 replications in the main trials (Fig. 31). The results are thus very reliable, and represent stands with a normal density. The correlation between the protein contents of the varieties in consecutive years were significant in all cases. The number of varieties varied from year to year, depending on alterations in the variety assort-

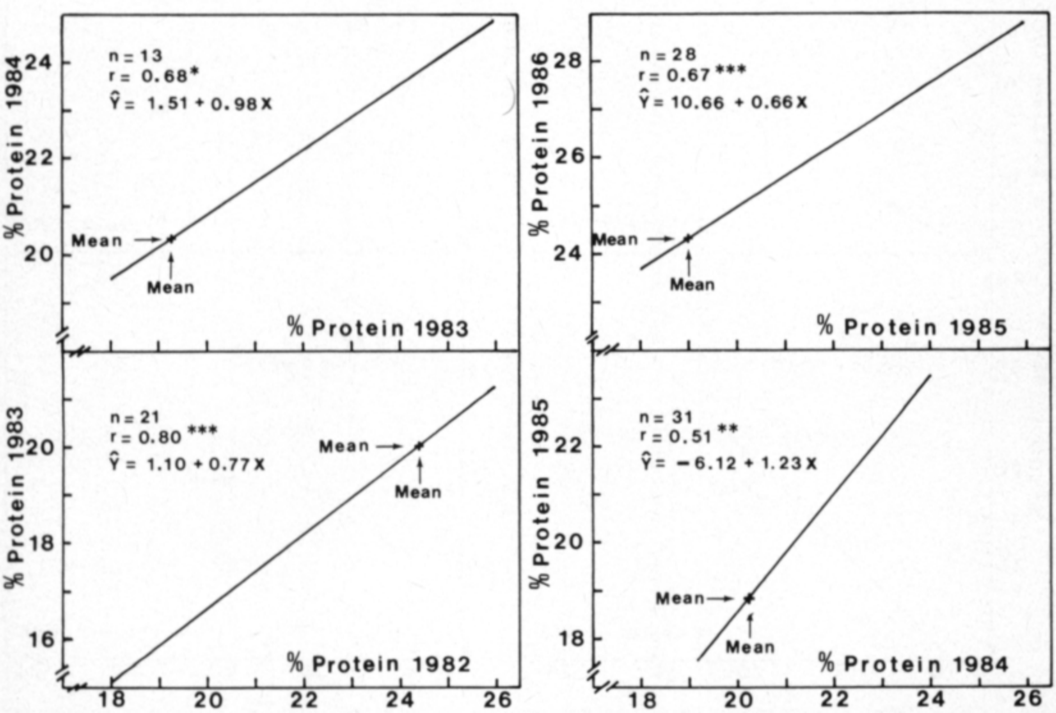


Fig. 31. Correlation between protein content of the varieties and regression in successive years. Main trials.

ment over the years. According to the results of regression analysis (Fig. 31), the protein content of a variety explained 64, 46, 26 and 45 per cent of the protein content during the following year. This is the effect of a variety on protein content.

As was the case in the main trials, the correlations between the protein content of varieties in consecutive years were also significant in the four-replicate preliminary trials (Fig. 32 left side). The explanatory values were 36 and 42 per cent respectively. Somewhat weaker relationships were obtained when the protein contents of the breeding lines in the preliminary trials were compared with their protein content in single small plots (Fig. 32 right side). The explanatory values were only 20 and 29 per cent respectively. The reason for this was the larger random variation of the single plots. A significant correlation, although with a somewhat lower explanatory value of 17 per cent, was found between the protein contents of the breeding lines in the line row yields and in the small plot yields (Fig. 33). The above effects of genotype on protein content are perhaps much stronger than e.g. WEBER (1981) has suggested. According to WEBER, the additive variance, which will be exploited in breeding, was only 15—20 per cent of the variance caused by other factors. QUEDNAY and WOLFF (1978) obtained interactions between mutation lines and year in the protein content.

Large yearly differences occur between the averages on the regression lines. This is of no disadvantage in selection in practical breeding, when the behaviour of breeding lines is consistent compared to the mean level of the material. BINGEFORS et al. (1979 b) also considered relative differences of varieties in protein content to be very constant. Large yearly variation in the protein content of individual

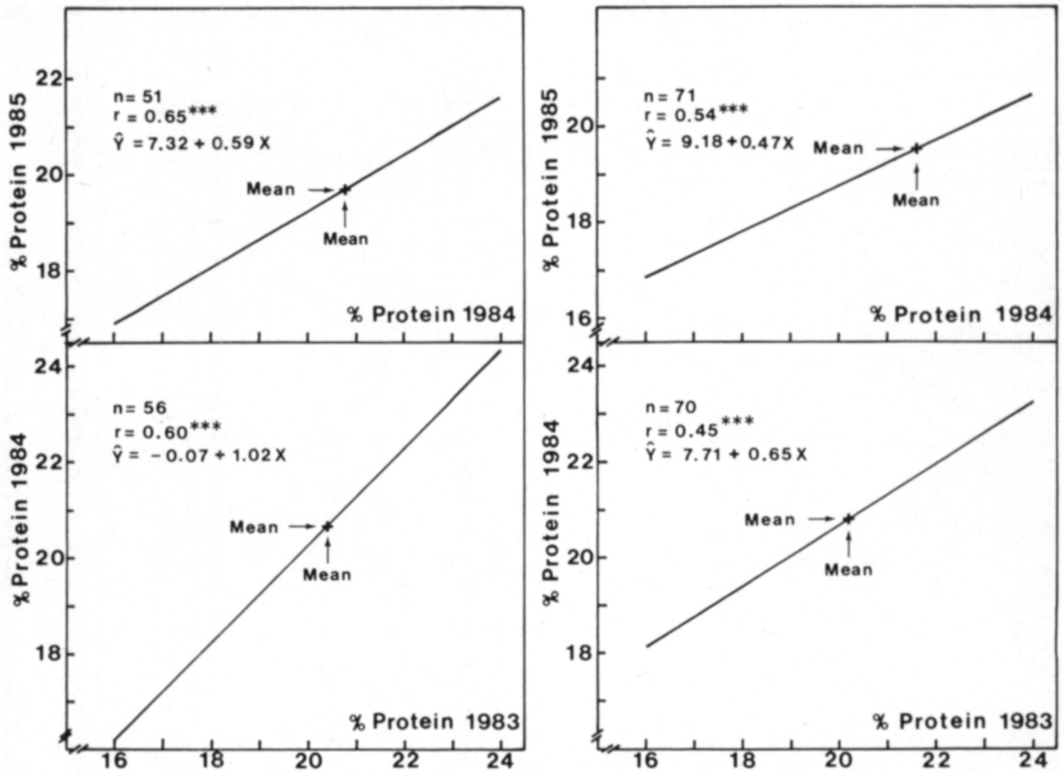


Fig. 32. Correlation between protein content of the breeding lines and regression in successive years. Preliminary trials on the left; single plots vs. preliminary trials on the right.

lines, compared to the medium level of a material, indicates poor adaptability of a line or defects in *Rhizobium* symbiosis.

The protein content of a variety has a certain predictive value established by the regression analysis. It is a sufficient basis for making rejections when breeding lines are being selected for continuation. When the lines with the very lowest protein content are rejected, it is unlikely that very good lines with respect to this character would be lost. A great number of lines must be rejected in all instances. This is already the case at the line row stage. It has not been possible to perform protein analysis on single plant yields in the program. SLINKARD (1981) found that the random variation between single plants is too large to make selection possible.

3.2. *Variation in the protein content of new breeding lines*

The protein content distribution of the line row yields in 1984 and 1985 were of much the same shape (Fig. 34). The differences between the averages for the individual years were exceptionally large. The difference probably did not arise as a result of inequality of the materials, but rather from the climatic dissimilarity. Considering both years the range was 15.4—27.6 per cent. This was also the range which was available when selecting lines for continuation. The collection of the Weibullsholms genebank had variation which reached a higher upper value; its range was from 15.8 to 31.0 per cent (BLIXT 1978 b). For the sake of comparison, the range of the ICARDA international collection of faba beans had a range of 18.6—37.8 per cent protein in dry matter in 2280 samples (SAYED et al. 1982). It should be remembered that although the variation shown in Fig. 34 represented unselected material, selection for morphology and growing time had been done over many generations. This selection has probably excluded long-stemmed and late plants with high protein content.

3.3. *Effect of cross combination on protein content*

3.3.1. Protein content of the line material in 1984

The pea material presented by frequency distributions in Fig. 34 is divided according to pea cross combination in Tables 25 and 26. The statistical significances between the cross and grand mean of all the material were determined by the t-test. The protein analyses have been done from the line yields representing 30—40 plants, grown at a row distance of 20 cm.

In the 1984 material, 7 crosses had a significantly higher protein content and 6 crosses a significantly lower protein content than the average. The range of averages of the cros-

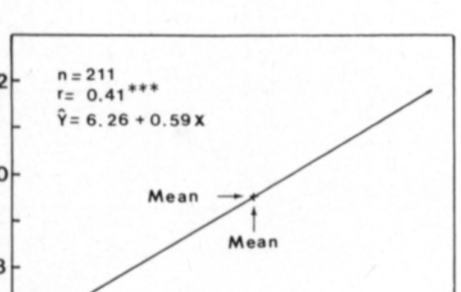


Fig. 33. Correlation between protein content of the line rows in 1984 and single plots in 1985 and regression.

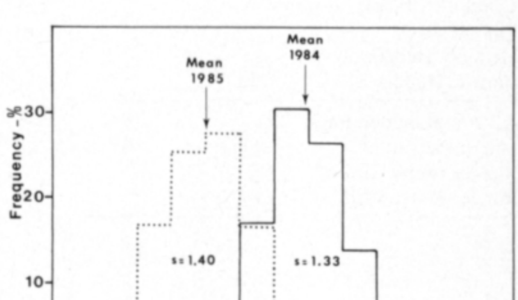


Fig. 34. Frequency distribution of protein content in the line row yields. 533 lines in 1984, 425 lines in 1985.

Table 25. Crude protein content of different crosses from single plant pedigree rows 1984. Mean of 4 or a greater number of lines.

Cross	Crude protein			
	n	%	s	t
Frimas/Tammi	11	24.35	1.33	5.83***
L 1837/Hja 51237	5	23.74	1.03	3.74*
Filby/Vreta	10	23.54	0.89	5.44***
Cisminskij rannij/Wensum	5	23.34	2.21	1.34
L 1880/Filby	5	23.10	2.48	0.98
Filby/Sv U 09901	20	22.96	1.23	3.45**
J.I. 758/Tammi	24	22.92	0.74	5.97***
Omskij/Sv U 09901	15	22.90	1.15	2.96*
Wensum/Vreta	5	22.88	0.91	2.12
L 1042/Filby	9	22.84	1.55	1.59
J.I. 502/Tammi	24	22.73	0.99	3.53**
J.I. 776/Filby	5	22.66	1.86	0.77
Frisson/Tammi	6	22.43	0.71	1.42
J.I. 423/Sv U 09901	4	22.30	0.53	1.08
Frisson/Filby	21	22.28	0.88	1.39
Koroza/Vreta	5	22.28	0.62	0.97
J.I. 180/Tammi	7	22.24	0.98	0.58
Omskij/Wensum	12	22.23	1.06	0.69
Filby/Hja 51202	9	22.08	0.90	0.47
L 1692/Hja 51326	6	22.03	0.49	0.07
J.I. 423/Tammi	9	21.94	0.84	0.27
Krasnoufimskij 70/Filby	24	21.93	1.04	0.39
L 5038/Heikka	4	21.87	0.80	0.36
Filby/Hja 51326	12	21.87	0.93	0.56
Frimas/Heikka	6	21.83	0.99	0.44
J.I. 229/Filby	8	21.75	0.89	0.84
J.I. 180/Wensum	4	21.75	0.90	0.59
Filby/Hja 51237	17	21.67	1.05	1.36
Filby/Wensum	23	21.66	0.87	1.97
Wensum/Hemmo	16	21.56	0.92	1.97
Wensum/Sv U 08630	11	21.51	0.71	2.40*
Koroza/Wensum	9	21.50	0.86	1.78
L 5038/Wensum	11	21.48	0.76	0.53
Barton/Proco	12	21.47	0.98	1.92
Frimas/Hemmo	4	21.32	1.50	0.92
L 1734/Proco	4	21.27	1.15	1.29
L 5242/Filby	32	21.23	0.82	5.39***
J.I. 502/Sv U 09402	7	20.97	1.47	1.88
Eaton/Heikka	29	20.93	1.01	6.02***
Cisminskij rannij/Wensum	4	20.90	0.70	3.17
Filby/Proco	10	20.71	0.98	4.20**
Hemmo/Heikka	9	19.98	1.03	5.91***
Barton/Heikka	11	19.62	0.89	8.91***
All round seeded lines	533	21.96	1.33	—
Marrowfats	26	23.55	0.82	9.51***
Range, round seeded		18.0—27.6		
Range, marrowfats		22.3—25.2		

ses was from 19.6 to 24.4 per cent, and the range of single lines 18.0—27.6 per cent. The breeding lines have been selected for continuation according to protein content. Cross combinations will therefore not be considered. Possible information about the average protein content of a cross could be utilised in later steps in breeding. For instance, the best protein contents were obtained from the cross Frimas/Tammi in the line row material (Table

Table 26. Crude protein content of different crosses from single plant pedigree rows 1985. Mean of 4 or a greater number of lines.

Cross	Crude protein			
	n	%	s	t
WIR 10//Filby/Proco	4	20.90	0.37	9.99**
J.I. 758/Wensum//Double One	20	20.85	1.39	5.88***
J.I. 502/Tammi//J.I. 776	7	20.77	1.12	4.11**
Onward//Filby/Proco	15	20.66	1.12	5.63***
J.I. 776/Filby//New Season	8	20.47	0.67	6.07***
J.I. 538/Filby//J. I. 538	10	20.14	0.50	7.00***
WIR 10//Proco/Tammi	10	20.13	0.73	4.76**
Onward//Filby/Wensum	11	19.88	1.02	2.77*
Hungarian marrowfat//L 1692/Hja 51326	10	19.73	0.43	5.09***
J.I. 538/Filby//New Season/Filby	12	19.53	0.58	2.99*
Wensum/Hemmo//Hja 51560	4	19.40	0.42	1.74
J.I. 423/Tammi//New Era	11	19.50	0.73	0.57
Hungarian marrowfat//Frogel/Wensum	7	19.07	0.75	0.15
J.I. 538/Eaton//J.I. 502	21	19.02	0.92	0.03
Gloriosa//Proco/Tammi	4	18.95	2.08	0.08
New Era/Wensum//J.I. 502	25	18.94	1.19	0.39
J.I. 423/Sv U 09901//J.I. 776	9	18.91	0.94	0.38
Judovi Györgyi//Proco/Tammi	5	18.90	0.48	0.60
J.I. 752/Tammi//New Era/Tammi	26	18.84	1.13	0.85
L 5242/Filby//Hja 51560	18	18.81	0.90	1.03
New Era/Wensum//Filby/Hja 51326	12	18.77	1.29	0.70
J.I. 502/Sv U 09402//Double One/Wensum	5	18.76	0.38	1.60
New Season/Filby//J.I. 423	8	18.74	0.84	0.98
Hungarian marrowfat//Frisson/Filby	7	18.71	1.10	0.76
J.I. 236/Hja 51237//J.I. 776/Hja 51237	5	18.68	1.38	0.57
L 5242/Vreta//Hja 51560	9	18.60	1.39	0.93
J.I. 758/Tammi//J.I. 758	14	18.37	0.87	2.82*
J.I. 502/Tammi//J.I. 502	11	18.18	1.26	2.23*
J.I. 758/Tammi//J.I. 776	4	18.12	1.30	1.39
Hungarian marrowfat//Barton/Heikka	8	18.00	0.74	3.95**
Hungarian marrowfat//Proco/Tammi	6	17.75	0.37	8.53***
J.I. 423/Sv U 09901//Filby/Sv U 09901	39	17.65	1.16	7.40***
New Era/Tammi//J.I. 502	12	17.64	0.87	5.53***
All lines	425	19.03	1.40	—
Range		15.4—23.2		

25). As in the crosses Filby/Vreta and J.I. 758/Tammi, a large number of lines and a small standard deviation improve the reliability of the interpretation of high protein content. If the yield from populations (F_1, F_2) with an exceptionally high protein content has been stored, it can be sown again for expanded selection. This is particularly relevant if the number of originally selected plants is small, e.g. under 100. A renewed cross can also be done.

Unbiased estimates of the effect of single parent varieties on protein content will not be obtained, because the cross program has not been planned for this purpose. On the basis of the table arranged in decreasing order of protein content one can, however, draw some conclusions about the ability of a certain variety to produce descendants with a high protein level. Descendants of Filby and Wensum can be found at all protein content levels. No descendant of Tammi has a low protein content. All crosses with Proco and Heikka are poorer than the average. Most of the parent varieties were located randomly in the table. The success of a cross is also dependent on the other parent.

The average protein content of marrowfats descending from different crosses has also been estimated. It is significantly higher than that for round-seeded lines. SLINKARD (1981) also noticed a higher protein content of marrowfats. The range of the protein content of marrowfats was narrow, perhaps due to the small number of lines.

3.3.2. Protein content of the line material in 1985

All the pea material had an exceptionally low protein content in the growing conditions of 1985 (Table 26). However, this is no obstacle in comparing the crosses. Ten crosses were significantly better and six poorer than the average. The averages of the best crosses exceeded the average for the whole material by nearly two per cent units. A new, broadened single plant selection was carried out from those populations. There were no possibilities to draw conclusions about the ability of single parent varieties to transmit the high protein content character to the progenies. The crosses were more complicated than usually, because the purpose was to gather resistance genes from different sources against the most important diseases. Toward the end of the table the cross J.I. 423/Sv U 09901//Filby/Sv U 09901 is worth noticing. A great number of lines have been selected from it to continue for reasons other than protein content earlier in the single plant selection phase. It seems improbable that varieties with a high protein content could be found from this group.

This line material had a narrower range of protein content than the material for 1984. This applies to both the single lines and the cross averages. Although the material was also smaller, it is obvious that both very good and very poor protein contents can more easily be found from two parent crosses than from complicated cross combinations. SWIECICKI et al. (1980) suggested that breeding for high protein content was most easily carried through by crossing varieties with a medium protein content. This could not be verified with the line material in 1984—85 because the protein content of the parent varieties was only partly known.

3.3.3. Protein content of multiplication plots

The multiplication plots (single plots 8 m^2) in 1984 had not earlier been selected on the basis of protein content (Table 27). The cross Filby/Garfield clearly proved to be the best in the material. The advantage of this cross has been verified later by the high protein content of its progeny in large trials. Very high yielding lines with a low protein content have been developed from the crosses Proco/Tammi and Filby/Heikka, which had a medium protein

Table 27. Crude protein content of different crosses from multiplication plots 1984. Mean of 4 or a greater number of lines.

Cross	Crude protein			
	n	%	s	t
Filby/Garfield	17	21.66	0.69	3.77**
Filby/Hemmo	4	21.40	1.43	0.52
Filby/Hja 51271	7	21.27	1.29	0.64
Proco/Tammi	20	21.08	1.34	0.18
Filby/Wensum	32	21.02	1.25	0.03
Filby/Heikka	33	20.86	1.18	0.96
Frisson/Filby//J.I. 423/Wensum	6	20.66	0.96	0.93
Frisson/Filby//Panu	6	18.51	0.46	13.34***
All lines	137	21.03	1.30	—
Helka, standard	10	20.90	1.08	0.40
Range	137	18.1—23.7		

content. The standard variety Helka did not differ from the average for the breeding lines. The range of protein content was small.

The multiplication plots in 1985 (Table 28) were composed of material which had already been selected for protein content once. Since selection was also done for many other characteristics the number of lines was reduced by half. Obviously the selection for higher protein effectively increased the average, because the multiplication plots had a higher protein level than the line rows (Table 26) in the same year. Compared to the table for 1984, there were large changes in the ranking between crosses owing to the rejection of low protein lines. The cross Krasnoufimskij/Filby, which was placed only on the medium level in 1984, proved to be the best. The cross Frimas/Tammi gave a very reliable picture of its ability to impart a high protein content to its progeny. The lines descending from this cross were better than the average in successive years. The cross Eaton/Heikka was poorer than the average in both years. The range for single lines was fairly wide, indicating a further need to discard the poorest lines. The marrowfats had a significantly higher protein level than the round seeded lines. Compared to the commercial standard variety Helka, all the crosses were significantly better in protein content. According to this, high protein material will appear in variety trials in the immediate years.

3.4. *Importance of selection for protein*

The pea is classified as medium high in protein when used for raw material in feed (Bingefors and Sjödin 1969, Thomke 1979, Grosjean 1985). Low protein varieties do not fulfill this criterion, and their cultivation will cease because of marketing difficulties; when

Table 28. Crude protein content of different crosses from multiplication plots 1985. Mean of 4 or a greater number of lines.

Cross	Crude protein			
	n	%	s	t
Krasnoufimskij 70/Filby	11	21.24	0.72	8.58***
Frimas/Tammi	7	20.90	1.37	2.96*
Wensum/Sv U 08630	6	20.60	0.71	4.22**
Filby/Vreta	4	20.47	0.78	2.85
Frisson/Tammi	4	20.45	0.92	2.34
Wensum/Vreta	4	20.27	0.40	4.50*
Wensum/Hemmo	5	20.16	0.41	4.26*
Filby/Sv U 09901	7	20.06	1.00	1.83
L 5242/Filby	17	19.66	0.93	1.30
Omskij/Wensum	9	19.59	1.41	0.47
J.I. 758/Tammi	14	19.42	0.71	0.28
L 1042/Filby	7	19.21	1.19	0.34
Filby/Hja 51326	7	19.00	1.19	0.82
L 5038/Wensum	6	18.95	0.89	1.15
J.I. 423/Tammi	6	18.92	1.15	0.96
Eaton/Heikka	16	18.89	0.80	2.39*
Frisson/Filby	10	18.50	0.53	5.01***
Filby/Proco	4	18.45	0.92	3.00
Filby/Hja 51237	7	18.17	0.94	3.36*
J.I. 502/Tammi	6	18.15	1.06	2.82*
Filby/Wensum	7	18.14	0.54	5.98***
Filby/Hja 51202	4	18.12	1.53	1.62
All round seeded lines	198	19.37	1.34	—
Helka, standard	20	17.63	1.04	7.46***
Marrowfats	12	22.93	0.94	13.08***
Range		15.7—24.4		

a variety assortment increases, the need for a higher protein content in a variety will be emphasized. A too low protein content will prevent a variety from being accepted on a list of recommended varieties in many countries. To avoid fruitless work, lines of this kind should be discarded at an early stage. In current breeding practices the first selection to discard lines is done when the breeding lines are transferred for growing as a crop in line rows in generation F_6. Later in the program the protein content of every line will be checked through gradually widening trials. Kaul and Garg (1982) considered evaluation of protein content over several years to be very important.

In several studies protein content and seed yield have been found to be correlated negatively, but weakly if at all (Bingefors 1958, Bingefors et al. 1979 b, Slinkard 1981, Swiecicki et al. 1981, Krarup 1982). So far in this study, however, it has been established that protein content is able to explain a small, but significant proportion of the protein yield. Improvement of the protein content will help breeding for protein yield, because the yield level does not necessarily decrease at the same time.

In breeding, the protein content cannot be considered as an independent characteristic. Earlier in this study the dependance of protein content on growing time was verified. Co-adaptability between the pea variety and *Rhizobium* strains in the soil at the growing site can have an effect on protein content (Hobbs and Mahon 1983, Brewin et al. 1985). Pea genotypes may also have a different capacity for nitrate reduction in the roots and shoots (Jensen 1986 b). The nitrogen supply of the seeds and the protein content may be dependent on this. However, our knowledge of the regulatory processes involved in seed protein accumulation and the genetic components responsible for these traits is still incomplete (Müller 1984). It is advisable to select single plants and line rows when plants are in the vigorous growth stage. In conditions where nitrogen application is lacking, defects in the biological nitrogen fixation of a genotype will be observed visually. The differences are especially distinct in stress situations; selection must be directed at "well growing" plants or lines.

4. Results of the breeding programme

4.1. Characteristics of the varieties in pure stands

The results for the varieties in different trials are summarized in Tables 29, 31 and 32. The computation practice was pair comparison analysis, in which all varieties were compared to the same standard variety, Proco. Since only a small number of trial results were

Table 29. Varieties in pure stand in 1982—86 in increasing order of earliness. Standard variety Proco. Number of trials, seed yield and protein yield.

Variety	Seed yield, Proco kg/ha = 100		Protein yield kg/ha
	n	relative value	
Barcota	3	118	+ 280*
Tammi	9	103	+ 70
Hemmo	13	104	+ 120
Kimo	5	127	+ 200
Finale	8	91	— 70
Hja 51821	3	141**	+ 360**
Allround	9	90	—110
Hja 51824	4	125	+ 230
Heikka	9	92	— 60
Hja 52257	3	137**	+ 400**
Helka	9	111	+ 100
Hja 52259	3	133	+ 380
Dryden	3	124	+ 180
Hja 52118	4	157**	+ 360**
Esa	5	129*	+ 300*
Osmo	7	116*	+ 160*
Hja 52096	4	110	+ 120
Filby	8	76*	—200*
Hja 51893	8	125**	+ 210**
Hja 52024	4	142**	+ 220*
Hja 52005	4	179*	+ 270*
Hja 51850	9	129**	+ 180**
Panu	11	114*	+ 40
Pika	11	104	+ 30
Proco	16	3420	680
Hja 52206	5	89	— 60
Hja 52208	5	106	+ 280
Hja 52093	4	114	+ 70*

obtained for some lines and varieties, statistical significances for the differences could not always be found.

Among the late varieties, Hja 51821 expressed a very high yield compared to the standard variety (Table 29). Concerning the fairly early varieties, Hja 52257, Hja 52118, Esa and Osmo were significantly better in yield than the standard. Of the early varieties Filby was a poor producer. The lines Hja 51893, Hja 52024, Hja 52005, Hja 51850 and Panu proved to be surprisingly good yielders considering their growing time. The lines which were earlier than Proco did not differ significantly in yield. According to these results, the two most promising lines were Hja 52118 and Hja 52005. However, both were included in only four trials.

The success of varieties growing under conditions differing in favourableness was studied by the FINLAY-WILKINSON (1961) regression method (Table 30). Significant differences were found between the varieties. GOTTSCHALK (1978) and KAUL et al. (1980) also observed differential behaviour of lines resulting from genotype-environment interaction. The coefficient of sensitiveness (regression coefficient) indicates the reaction of a variety to the growing conditions compared to the mean for the varieties. Since the number of the trials was small, however, it was not possible to obtain a reliable impression of the performance of some of the varieties. The varieties Tammi, Hemmo, Hja 52118, Esa and also Hja 51850 indicated that they are adaptable to poor conditions, where their yields greatly exceed the species mean. Hemmo and Esa had a low degree of determination in the regression. Helka had yields 8 per cent higher than the species mean of every yield level. Finale, Heikka, Pika and Proco responded strongly to improving growing conditions. However, they were not able to compete with e.g. Kimo, Hja 52118 and Esa even in the most favourable conditions. Varieties which exceed the species mean at all yield levels will unquestionably do well in widespread cultivation. If a variety is undapted to poor conditions and has a high coefficient of sensitivity, it will succeed only now and then. Of the varieties

Table 30. Yield capacity of pea varieties compared with species mean at different yield levels by regression analysis. Pure stand trials in 1982—86.

Variety		Relative yield of variety at yield level (kg/ha)			Sensitivity coefficient	Determination coeff.-%
	n	2000	3000	4000		
Tammi	9	132	112	100	0.60*	69
Hemmo	13	113	104	97	0.78	49
Kimo	5	74	95	113	1.61	72
Finale	8	55*	71*	85	1.64*	90
Allround	9	61*	73*	83	1.45	88
Heikka	8	46*	67*	88	1.93*	87
Helka	9	108	108	108	0.99	92
Hja 52118	4	146*	132*	123*	0.75	98
Esa	5	146	128	117	0.68	35
Osmo	7	93	100	104	1.16	89
Filby	8	77	76*	75*	0.96	85
Hja 51893	8	85	97	106	1.33	89
Hja 51850	9	115*	111*	108	0.90	96
Panu	11	110	106	104	0.92	93
Pika	11	66**	80**	92	1.47*	95
Proco	16	65**	78**	89	1.45*	88
Hja 52208	5	76	77	78	1.04	74
Hja 52093	4	83*	80*	78*	0.90	99
Species mean		100	100	100	1.00	

studied above, Helka, Hja 52118, Esa, Hja 51850 and Panu are the most suitable for cultivation in Finland. Difficulties will arise in comparing the previous lines with the extremely early ones, which naturally cannot compete in yield. Hja 52093 seems to be well adapted, however.

The best varieties in seed yield were also generally the most productive in protein yield. The protein content caused certain alterations in the ranking of the varieties. The most effective protein producers were found from among the late and rather early varieties. The varieties Hja 51821, Hja 52257, Hja 52259 and Hja 52118 are especially effective protein peas. Their protein yield reached about 1000 kg/ha.

Large differences were found in the growth rate of small plants when examined 10—15 days after emergence (Table 31). However, this was not closely connected with the growing time. Several lines originating from the cross Filby/Wensum, such as Hja 52118, Hja 52096, Hja 52206, Hja 52208 and Hja 52093, were very rapidly growing afila-peas, as well as the market variety Dryden. Some afila-peas proved to be slowgrowing, like Esa and Osmo. Filby also grew slowly, perhaps as a result of its reduced stipules. According to the results a rapid growth rate does not necessarily affect the final yield, but competitiveness against weeds and an ability to compete with cereals in mixed stands are improved.

The date when flowering commenced was generally correlated with the growing time of a variety, although exceptions to this were observed. For instance, Tammi, Hemmo, Hja 51824 and Filby start their flowering very late. The varieties with a late flowering date did not flower for a very long period. The afila-varie-

Table 31. Varieties in pure stand in 1982—86. Agronomic characteristics.

Variety	Small plant growth rate 1—100	Flowering d	Flowering period d	Growing time d	Effective temp. sum dd	Stem height cm	Lodging %
Barcota	+ 2	+ 8*	+ 3	+16*	+130**	+25*	—22
Tammi	— 7	+11**	+ 3	+15**	+140**	+21**	—30*
Hemmo	—19	+ 9**	— 1	+12**	+120**	+ 9**	— 2
Kimo	— 6	+ 2	+ 6**	+11**	+100**	+13	—21
Finale	—22	+ 8**	— 3	+11**	+100**	— 7	—13
Hja 51821	+ 8	+ 4	+ 5	+10**	+ 90**	+19**	—23
Allround	— 6	+ 8**	— 2	+10**	+ 90**	+ 0	+ 1
Hja 51824	— 9	+11**	+ 1	+10**	+ 80**	+16	—14
Heikka	— 7	+ 8**	+ 4	+ 9**	+ 70**	+18**	— 5
Hja 52257	— 2	+ 6	+ 8	+ 9**	+ 80**	+17*	—12
Helka	— 4	+ 7**	— 1	+ 8**	+ 80**	+16**	—32**
Hja 52259	— 4	+ 6	+ 7	+ 8*	+ 80*	+15*	—18
Dryden	+36	+ 6*	+ 6	+ 8*	+ 80*	+29*	—14
Hja 52118	+31	+ 5*	+ 8	+ 7*	+ 70*	+27*	—10
Esa	—19	+ 8**	+ 4	+ 7*	+ 70	+11	—16
Osmo	—17	+ 8**	+ 1	+ 6*	+ 70*	+13**	—18*
Hja 52096	+25*	+ 4*	+ 4	+ 5	+ 50	+23*	— 6
Filby	—13*	+ 9**	— 2	+ 5**	+ 50**	+ 2	—29
Hja 51893	+ 4	+ 7**	+ 2	+ 5**	+ 50**	+20**	—11
Hja 52024	+ 1	+ 2	+ 4*	+ 4*	+ 60	+ 8	—32
Hja 52005	+13	+ 2	+ 6	+ 4	+ 70	+15**	—19
Hja 51850	+ 4	+ 6**	+ 1	+ 4**	+ 30*	+14**	—24**
Panu	— 7	+ 2**	+ 1	+ 4**	+ 40**	+15**	—25**
Pika	—11	+ 1*	+ 1	+ 2**	+ 20**	+ 4	—32**
Proco	64	42	17	91	890	44	46
Hja 52206	+25*	— 2**	+ 4	— 0	— 10	+13**	—27*
Hja 52208	+33*	— 2	+ 3	— 4*	— 30*	+11*	—15
Hja 52093	+36*	— 1	+ 0	— 5	— 50	+ 6	— 3

ties Kimo, Hja 51821, Hja 52257, Hja 52259, Dryden, Hja 52118, Hja 52024 and Hja 52005 possessed a long flowering period which lasted for over three weeks. A feature common to these varieties was their high productivity. Too short a flowering period will obviously prevent a variety from producing top yields.

The standard variety Proco is very early, and hence nearly all the other varieties were significantly later. The range of the growing time was wide, reaching three weeks. The maximum growing time for a variety for Finland is at most ten days later than Proco. The corresponding effective temperature sum is 980 degree days (dd). The earliest varieties in the comparison, Hja 52208 and 52093, have been bred for possible cultivation in the central parts of Finland.

Lengthening the growing time by one day corresponded to an increase of 10 dd in the effective temperature sum. The effective temperature sum requirements of the latest varieties were smaller, however.

None of the varieties in the comparison were clearly longstemmed. Finale had the shortest stem and Dryden the longest compared to Proco. The proposed stem height classification of the new pea material is as follows: low stemmed below 50 cm, semi-high stemmed 51—90 cm and tall above 90 cm. This classification is different from that proposed by Makasheva (1983), in which the class for very high-stemmed peas ranged from 151 cm to 300 cm. Most of the varieties, including the best yielding genotypes, were semi-high stemmed. Finale, Allround, Filby, Pika, Proco and Hja 52093 were low stemmed. None of them had a very good yield.

Proco, a leafed variety, together with Hemmo and Allround, had one of the poorest lodging resistances. Several commercial varieties, such as Tammi, Helka, Filby, Panu and Pika, possessed a much better lodging resistance than Proco. The afila-character alone was no guarantee of good lodging resistance, since obvious differences were found between afila-genotypes as regards this character. The best varieties were already so lodging resistant that it has decisively improved the status of the pea among field crops. A susceptibility to lodging is no longer an obstacle to large-scale cultivation of this crop.

Judging by Finnish standards, Proco has seeds of medium size; its thousand seed weight of 248 g would, however, be judged small in many countries (Table 32). A small seed size has been favoured in northern countries since it helps to minimise difficulties in harvesting and to decrease sowing seed costs. For instance, the varieties Heikka, Hja 52257, Hja 52259 and Hja 51850 had a very low thousand seed weight. On the other hand, Finale, Allround and Hja 52096 already had an unfavourably large seed size.

The environmental conditions prevailing in different years and the varieties obviously in-

Table 32. Varieties in pure stand in 1982—86. Quality characteristics.

Variety	Tsw. g	Crude protein %	First class seeds %	Cooking rate 60 min. %
Barcota	+ 8	+2.8*	—19*	— 2
Tammi	+ 19*	+0.9	— 9*	— 3
Hemmo	+22**	+2.4**	—18*	+14
Kimo	— 1	+0.0	— 2	+ 0
Finale	+82**	+0.1	—16*	+ 6
Hja 51821	—20	+1.1	— 4	— 7
Allround	+52**	—0.9	—19**	—16*
Hja 51824	+ 8	+0.9	—15*	—19
Heikka	—92**	—0.1	— 9	—29**
Hja 52257	—52*	+2.6	—20	— 4
Helka	—19	+0.4	+ 5	—12
Hja 52259	—53*	+2.4*	—18	+ 7
Dryden	— 1	+2.0	—18	—11
Hja 52118	+34*	+0.5	+ 6	—12
Esa	—30*	+1.8	—16	— 5
Osmo	—43**	+0.6	+ 5*	—14
Hja 52096	+38**	+1.7	+14	—14
Filby	—13	—0.3	— 8	— 5
Hja 51893	— 1	+1.8	—12	— 2
Hja 52024	+10*	+0.8	+ 6*	—11
Hja 52005	— 6	+1.0	+ 2	— 7
Hja 51850	—49**	+0.4	+ 1	— 6
Panu	—13**	—1.4**	+ 2	—18*
Pika	— 9*	+0.5	+ 2	+ 1
Proco	248	19.6	80	74
Hja 52206	+12	+0.1	— 4	— 9
Hja 52208	+ 8	+1.6*	+ 7	+ 8
Hja 52093	— 4	+1.4	+ 6	—11

teracted with protein content, because only a few varieties differed significantly from Proco. Of the late varieties Barcota and Hemmo clearly had a high protein content. As regards the quite early varieties, Hja 52259 was significantly better than Proco, and of the extremely early ones Hja 52208 showed a similar trend. Panu had a significantly lower protein content than Proco. Peas grown under Finnish conditions tend to have a rather low protein content in comparison with peas cultivated in more southerly conditions. This result is in agreement with MAKASHEVA (1983), who suggested that the reason is the low temperature during the ripening period.

Proco, being an early variety, generally produced a seed yield of very high outer quality. Although later than Proco, the afila-varieties Osmo, Hja 52096 and Hja 52024 nevertheless produced a yield of even higher quality. The reason for this was the decrease in lodging, which caused less seed damage. The late varieties suffer too much from quality losses in the Finnish climate, even though they would be of the afila-type. This is one of the reasons why the varieties designed for Finland should not be more than ten days later than Proco.

The rate of softening of seeds when cooked is a quality factor of peas for human consumption. The standard variety Proco is considered to have a medium cooking rate. Only a few significant differences were found between Proco and the varieties, probably due to the small number of observations. No variety had a significantly better cooking rate than Proco. On the other hand Allround, Heikka and Panu had a much poorer cooking ability. Their cooking quality is already of doubtful value.

The most promising protein peas for Finland are introduced on the basis of the results of the pure stand trials. The maximum growing time rules out those varieties which are over ten days later than Proco. The quite early variety Hja 52118 possesses a high yield capacity in variable conditions. Its yield is also of good quality. The early varieties Hja 52024, Hja 52005 and Hja 51850 have a very high yield considering their growing time. Moreover they possess good lodging resistance and good quality as a protein pea. Hja 51821 and Hja 52257 have an extremely high seed and protein yield. However, their long growing time will limit cultivation to the southernmost part of Finland.

4.2. Characteristics of the varieties in mixed stands

Mixed cropping of pea lines with cereals in the preliminary trials indicated the adaptation of a pea genotype in a mixed stand. It is a matter of breeding for coadaptation as e.g. with timothy and red clover (JOY and LAITINEN 1980). Proco, an early variety which has long been cultivated as a leading variety in Finland, was used as the standard variety in the pairwise comparison (Table 33). It has been cultivated much in mixed stands with sparsely spaced cereals. Varieties for which results were available from at least three years were included in the comparison. Lines which were discarded on the basis of the results for 1986 were omitted.

The total yield for Proco, including peas and cereals together, was 4420 kg/ha, which is a high quantity under Finnish conditions (Table 33 A). The proportion of peas out of the total yield was high in all mixes. Owing to the small number of trial years, however, no variety was distinguished from Proco as being significantly better in yield. This applies to both pea yield, total yield and total protein yield. Total yield and total protein yield are decisive from the point of view of protein production. A protein variety of high economic value must also be high in total yield. Such varieties appear to be Hja 52092, Hja 51821, Hja 52008, Hja 52128, Barcota and Hja 52104. The varieties cultivated in pure stand (Hemmo, Proco) were not successful. All the other varieties and lines in the comparison, except for Heikka, were afila-peas. However, because they were not cultivated in pure stands in the trials, there was no possibility to make a corresponding comparison. The commercial

Table 33. Varieties in mixed stand in 1983—86. Standard variety Proco. Varieties in increasing order of earliness.

A. No. of trials and yield.

Variety	Pea yield Proco kg/ha = 100		Total yield kg/ha	Total protein yield kg/ha
	n	kg/ha		
Hemmo, pure stand	5	80	—1420*	—140
Hemmo	7	99	— 60	+110
Tammi	5	101	— 140	+ 0
Hja 52008	3	120	+ 650	+140
Barcota	3	120	+ 470	+180
Helka	4	100	— 150	— 10
Patu	3	112	+ 310	+ 90
Hja 51821	3	120	+ 670	+ 50
Heikka	5	77	— 730	—140
Osmo	3	100	+ 80	— 50
Hja 52092	3	130	+ 820	+190
Hja 51893	4	109	+ 50	+110
Hja 52086	3	110	+ 290	+ 90
Pika	3	87	— 330	— 50
Panu	4	109	+ 360	+ 30
Hja 51663	4	114	+ 460	+ 70
Hja 52005	3	114	+ 450	+100
Hja 51850	3	107	+ 80	+ 20
Hja 52104	3	121	+ 460	+140
Hja 52128	3	119	+ 640	+160
Hja 52024	3	112	+ 300	+ 80
Proco, pure stand	5	103	— 560**	—100**
Proco	7	3610	4420	810
Hja 52208	3	108	+ 420	+150
Hja 52093	3	89	— 230	— 40

varieties Tammi, Helka, Pika, and Heikka proved to be poor protein producers in the mixed stand. In contrast, Barcota, Patu and Panu did fairly well. The adaptability of a variety to mixed cropping has been pointed out in many earlier studies, e.g. PESOLA (1938, 1942) and ANTTINEN (1961). A drought-sensitive variety will grow poorly in mixed cropping, since drought sensitiveness will be accentuated in a mixed stand (HÄNNINEN 1956). The varieties used in the earlier experiments were leafed peas. The afila-genotype and cereal together, however, remodel the ecological conditions of the crop. Each pea genotype-cereal from unique combinations, the yielding capacity of which should be examined separately. As regards afila-peas, too, it may be true that the characteristics of a pea variety are more decisive for the total yield than the characteristics of a cereal variety (SAASTAMOINEN 1984). In this case the productivity of pea lines may be preliminary investigated in one pea-cereal ratio in a mixed stand.

It is interesting to compare the best total yields of a pea-cereal mixture with the cereal yields from a pure stand cultivated under approximately the same conditions. The best total yields exceeded 5000 kg/ha. In the trials at Anttila Experimental Farm the best yielding barley and oat varieties had yield averages of about 6000 kg/ha over a fiver-year period (AIKASALO and KESÄLÄ 1985, REKUNEN 1985 b). Thus the best mixed crop combinations can reach 80—90 per cent of the yield level of the best feed cereal varieties. In comparison to this, SIMOJOKI et al. (1986) indicated that mixed stands of pea-oats produce nearly as high yields as pure oats. On the other hand, the best feed cereal varieties produced only 60—70 per cent of the protein yield, which was the level for the best pea-cereal mixed stands.

Large differences were found in the growth rate of the pea genotypes at the small plant stage (Table 33 B). Some fast-growing lines such as Hja 52092, Hja 52086, Hja 52104, Hja 52128 and Hja 52208 are capable of forming the best yielding mixed stands. They are all early enough for cultivation in Finland. To be sufficiently competitive in a mixed stand, however, a pea variety should possess a fast growth rate during the first weeks of the vegetative growth stage. Observations and selections for a high growth rate are thus necessary in breeding varieties for mixed cropping.

Only small differences were found between the genotypes as regards flowering time, and it was generally directly related to growing time. Vigorously growing genotypes (Hja 52092, Hja 52086) tend to flower for a long time. The pure stand cultivation of the varieties Hemmo and Proco extended their flowering period. According to the results from both pure stand and mixed stand cultivation, the ranking of the growing times of the varieties appears to remain unchanged. Thus the growing times of varieties can also be reliably monitored in mixed stands. Similarly, the stem height of genotypes can be safely measured from mixed cultivations. The final height of the stem is the decisive factor determining whether a pea variety would be competitive with vigorous cereals in mixed stands. The importance of giving precise advice on a varietal basis for mixed cropping should be stressed (Bengtsson 1984 b). In this, the characteristics of a cereal have to be taken into account to some extent.

B. Agronomic properties and quality of pea.

Variety	Small plant growth rate 1—100	Days to flower	Flowering period d	Growing time d	Height of crop cm	Lodging %	Tsw. g	Crude protein %
Hemmo, pure stand	—28	+ 8**	+ 5*	+15**	+13**	+17	+14	+3.3**
Hemmo	—24*	+ 8**	+ 0	+14**	+13**	+12	+32**	+3.4**
Tammi	—16*	+10**	— 1	+14**	+26**	— 7	+27*	+2.4*
Hja 52008	+ 3	+ 3*	+ 7	+10*	+23*	— 7	— 1	+0.7
Barcota	—17*	+ 8*	— 1	+10	+24*	+ 2	— 3	+1.6
Helka	—14*	+ 7**	+ 1	+10**	+19*	— 8	—14	+0.3
Patu	—18	+ 3*	+ 4	+ 8	+20*	—15	— 8**	+0.7
Hja 51821	— 4	+ 4	+ 2	+ 8	+24*	+ 2	+ 3	+0.4
Heikka	— 5	+ 7*	+ 2	+ 6*	+24*	+11	—86**	+0.9
Osmo	—20	+ 7*	— 1	+ 6	+13	— 7	—40*	+0.3*
Hja 52092	+23*	+ 2	+ 5*	+ 6	+35	+ 5	+ 3	+0.7
Hja 51893	— 3	+ 7**	+ 1	+ 5**	+20*	+ 2	+ 0	+2.2**
Hja 52086	+16	— 4	+11**	+ 5	+32*	— 5	— 9	+1.3
Pika	—13	+ 0	+ 1	+ 4*	+ 4	—21	— 5	+1.2
Panu	— 9	+ 2	+ 0	+ 4**	+14**	—14*	— 5	—0.5
Hja 51663	— 6	+ 3*	+ 0	+ 4	+19**	— 8	— 3	—0.5
Hja 52005	— 1	+ 1	+ 3	+ 4	+22**	— 4	— 3	+0.0
Hja 51850	— 7*	+ 5*	— 3	+ 3	+14	—14	—55*	+0.0
Hja 52104	+21	+ 2	+ 1	+ 3	+28*	+16	+30*	+1.2
Hja 52128	+17	+ 3	+ 2	+ 3	+18*	+ 0	— 1	+1.3
Hja 52024	—16	+ 2	+ 2	+ 2	+13	—13	+ 5	+0.3
Proco, pure stand	+ 4	+ 0	+ 1*	+ 0	+ 3	+30	—16	—0.2
Proco	73	44	17	91	49	21	233	19.1
Hja 52208	+18*	— 4	+ 3	+ 0	+13*	—12	+31*	+1.8
Hja 52093	+17	— 3	+ 1	— 2	+10**	—22	+ 7	+0.8

The low-stemmed standard variety Proco lodged only lightly in the mixed stand. Many of the afila-genotypes which were longer stemmed than Proco had an even lower degree of lodging. The best varieties in the mixed stand already matched the general level of the best cereal varieties as regards lodging resistance. Lodging resistance should always be considered together with the total yield of each separate mixed stand combination. For instance, the genotypes Hja 52008, Patu, Hja 52086, Panu, Hja 51850, Hja 52024 and Hja 52208 form very lodging resistant and productive mixed stands. Lodging resistance is of primary importance for safe cultivation under Finnish conditions. According to the results, well co-adapted mixed stands have as good a lodging resistance as the best cereals. A very sparse stand of cereal is enough to provide sufficient supporting effect.

Differences in seed size can also be safely analyzed from mixed stand yields. This also applies to protein content.

4.3. Varieties marketed from the programme

Some commercial varieties have been marketed during the course of the breeding programme. Furthermore, several breeding lines have been named for official trials in foreign countries.

Hankkijan Hemmo (= Hja 51103) was released in 1980. It originates from the cross Maro/Kalle in 1963. Hemmo is semi-high stemmed, leafed and a relatively late variety, which is cultivated as a soup pea. Its seeds are green.

Hankkijan Heikka (= Hja 51229), another leafed variety, was put on the market in 1983. It descends from the cross Hja 10949/K-2225 in 1970. Heikka is a rather early, semi-high stemmed and small seeded with a yellow seed colour. It has been grown especially in mixed stands for feed.

Hankkijan Tammi (= Hja 51277) was the first afila-pea from the programme. It descends from the cross Simo/Usatyj 5 in 1970. Usatyj 5 was the source of the *af*-gene. Tammi was released in 1984. It is green-seeded, semi-high stemmed and late. It is cultivated as a soup pea.

Helka (= Hja 51792) is a green-seeded afila-pea originating from the cross Proco/Hja 51221 in 1977. The latter is a sister line to Tammi. Helka is rather early, semi-high stemmed with a very good yielding capacity. It was marketed in 1986 as a protein pea. Helka has been included in official variety trials in many countries in 1987. It has been accepted on the list of recommended varieties in England in 1987.

Pika (= Hja 51666), an early ripening afila-pea, descends from the cross Proco/Tammi in 1978. It was released in 1986 as a variety for protein production and as pea soup raw material. Pika is green-seeded and low-stemmed, possessing fairly good yields.

Panu (= Hja 51667) is another early maturing afila-pea. It originates from the same cross as Pika and was also marketed in 1986. Panu is green-seeded and well adapted for mixed cropping. It is intended for feed.

Osmo (= Hja 51822) descends from the cross Filby/Heikka in 1978. It is a yellow-seeded afila-pea for protein production. Osmo has a small seed size and it is specially adapted to dry conditions.

Esa (= Hja 52254) is another yellow-seeded protein pea of afila-type. It is derived from the cross Filby/Garfield in 1978. Its seeds are small with a high protein content.

Barcota (= Hja 51842) originates from the cross Proco/Tammi in 1978. It is a green-seeded afila-pea with a high protein content. It has late maturity.

Kimo (= Hja 51845) is a sister line of Barcota much resembling it. Kimo has green seeds with a medium protein content. Its lodging resistance is high.

Patu (= Hja 52027) resembles Kimo being also a sister line to Barcota. It is earlier, however.

Summary and conclusions

The main objective of the present work was to verify the characteristics of the best adapted protein pea for cultivation in Finland. The characteristics of the varieties were studied separately for both cultivation in pure stands and mixed stands. The variability and breeding prospects of the protein content were examined in a large breeding material. The study material involved pure stand variety trials with two nitrogen application levels continued for seven years, and mixed stand trials with one nitrogen application level for three years. Young line material from three years was used as the material in studying the possibilities of breeding for protein content. The effect of the gene *af* on different pea characteristics was a central object in the studies. This gene causes leaflessness in pea. The investigations were based on the characteristics of stands with normal density, not on the characteristics of single spaced plants.

The present work is a part of the current breeding programme, which will be continued to produce new varieties.

An ideotype of protein pea for cultivation as pure stands in Finland:

The gene *af* brings about the afila-character, in which all leaflets are converted to tendrils. Since the stipules are of normal size they are called "semi-leafless" or afila-peas. The gene *st* brings about a drastic decrease in stipule size: they remain narrow and short.

Stipules which are too large weaken lodging resistance. A suitable stipule width is 30—35 mm and length 60—70 mm. Since the best yielding breeding lines, which are also among the best in lodging resistance, are afila-peas, the present breeding work is concentrated almost entirely on this leaf type. No leafed variety proved to have a sufficiently high lodging resistance. Owing to the small leaf area, the breeding lines possessing the gene *st* does not have a good enough yield. The pea variety for Finland has to be of the afila-leaf type.

The varieties which are well adapted to the growing conditions have between 13 to 16 nodes per stem. The earliest have the lowest number. The corresponding number of pod-bearing nodes is from 3 to 5. The highest yielding varieties have a stem height of from 61 to 94 cm, and the varieties for pure stand cultivation should have a stem height of this class. A height of 50 to 90 cm can be considered as semi-high. The afila-varieties generally have a thinner stem base than the leafed ones. However, this has no apparent effect on the lodging resistance. The large mass of tendrils of afila-peas improves the lodging resistance so strongly that differences in stem rigidity caused by variability in stem thickness become masked.

Some low-stemmed varieties have a high harvest index, up to 60 per cent. They are not among the best in yield. On the other hand, a very low harvest index indicates unadaptability of a variety. A harvest index of 54—58 per cent can be considered the optimum.

The afila-peas lodge less during the generative phase than the leafed ones. Early lodging at the end of flowering decreases the yield in many instances. Severe lodging at the time of ripening lowers the yield of leafed varieties, because losses in combining are large. Not even the afila-varieties are entirely free from lodging. Thus an increase in stem rigidity is the next breeding aim with high priority. A mean lodging of 30 per cent is the upper limit as a varietal characteristic of safe cultivation.

The afila-peas tend to have a smaller root system than the leafed peas. The number of *Rhizobium* root nodules is also smaller, likewise the nitrogen amount of the roots. However, differences between afila-varieties are found in these characteristics. The effect of root characteristics on the final yield remained unclear. Peas must be capable of effective symbiosis with *Rhizobium* and to produce high yields without nitrogen fertilizer application. The pea variety should possess a sufficiently large root system.

The amount of dry mass and protein in the shoots of both the leafed and afila-varieties are similar at the end of the vegetative growth phase. According to the results, it would appear obvious that the gene *af* has a strong effect on the nitrogen metabolism of roots but not of shoots.

Pea varieties have to possess so high a resistance against diseases, mainly against *Ascochyta* sp. and *Peronospora* sp., that no need for chemical treatment exists.

A too large seed size decreases the number of seeds per pod. The best yielding varieties have from 6 to 9 seeds per pod. The upper limit of the thousand seed weight can be specified as 270 g because a very large seed size is linked with a decrease in protein content but increased sowing seed costs. Thus a relatively small seed size should be combined with a large pod that remains green near to maturity. The crude protein content should exceed 23 per cent if possible. A white-flowered protein pea may well have a green or yellow seed colour. The varieties must be round-seeded for easier cleaning.

When the seed yield level and sufficient safety margin for ripening are taken into consideration, the best suited growing time for a pea variety is from 91 to 101 days. This is the same growing time class as for two-rowed barleys in Finland. Even earlier varieties are required for the northernmost cultivation zones. Varieties with a too short flowering period are sensitive to climatic stress conditions during the generative growth phase. On the other hand a very long flowering period causes late ripening. The flowering period should last from 19 to 28 days.

The mean hectare yield for varieties in pure stands is about 4 500 kg. This is 75—90 per cent of the average yield of barley varieties cultivated under the same conditions. The hectare yield of crude protein is 990 kg. New varieties must exceed these mean yields significantly.

An ideotype of protein pea for cultivation as mixed stands in Finland:

Varieties designed for use in mixed stands have to have somewhat different characteristics compared to those for pure stands. An especially important point is that afila-peas are also the most suitable genotypes for mixed cropping. A pea variety must possess a high growth rate after emergence in order to be competitive with the supporting cereal in height and growth. A large number of genotypes of this kind were found in the present breeding material. The best suited growing time is the same as that for pure stands, 91 to 101 days. Peas must also attain a higher final stem height of up to 80—100 cm: this is 10—20 cm higher than the optimum for pure stands. A good variety for mixed cropping has to be able to produce an almost fully lodging-resistant stand with a selected cereal variety. Too small a seed size is disadvantageous for the competitive ability of young pea plants in mixed stands. The optimum seed size is therefore from 200 to 270 g.

Biological nitrogen fixation of the variety has to be so effective that there is no need for nitrogen application when cultivated together with a sparse cereal crop. The crude protein content of seeds should exceed 23 per cent if possible.

The peas for mixed cropping must also be white-flowered, green or yellow in seed colour and round.

The mean total yields in mixed stands are about 4700 kg/ha. The hectare yield of crude protein is 900 kg. New varieties must exceed mean values for these yields significantly.

Breeding for protein content

The crude protein content is a distinct characteristic of a variety, irrespective of the fact that the environment affects it strongly. The protein content ranged from 15.4 to 27.6 per cent in the young line material. This variation is sufficiently large for effective selection. Varieties with a low protein content (below 21—22 per cent) do not meet the requirements of the feed industry. Lines with an exceptionally low protein content should and can be discarded during the course of breeding. In this way the protein level of the breeding material can be gradually improved. Evaluation of protein content over several years is considered to be very important.

Progenies from different crosses have significant differences in protein content. Information about the average protein content of a cross could be utilised in later steps in breeding. If the yield of an early population (F_1—F_2) with exceptionally high protein content has been stored, it can be sown again for expanded selection.

The negative correlation (r = —0.15**) between protein content and seed yield is so weak that the highest possible yielding variety can also have a good protein content. The size of the protein yield is mainly dependent on the seed yield. To a lesser degree, although significantly, it is dependent on protein content. A variety with the highest possible protein yield must exceed the average level also in seed yield. The varieties showing the highest protein yield have a protein content of 23—27 per cent.

In breeding, the protein content cannot be considered as an independent characteristic. For instance, early maturing peas especially tend to express a low protein content. Afila-varieties have a lower protein content than leafed varieties. Variation in protein content between afila-varieties is, however, so large that high protein lines can easily be selected from them. Coadaptability between the pea variety and *Rhizobium* strains in the soil can have an effect on protein content. Therefore it is very important to have the results of protein content from different trial sites where nitrogen fertilizer has not been applied.

Need for nitrogen fertilizer application

The higher nitrogen application level of 80 kg/ha does not increase pea yield in comparison with the 16 kg/ha level. In contrast, it enhances the protein content by 1 % and the protein yield slightly. The rise in protein yield is too small to justify the replacement of biological nitrogen fixation by nitrogen application. A pea variety must have such effective nitrogen fixation that it does not need fertilizer nitrogen. This also concerns cultivation with a sparse cereal stand.

Results of the breeding programme

Some named varieties have been marketed during the course of the breeding programme. Leafed varieties *Hankkijan Hemmo* and *Hankkijan Heikka,* as well as afila-varieties *Hankkijan Tammi, Helka, Pika* and *Panu,* are market varieties in Finland. *Helka* has been accepted on the list of recommended varieties in England in 1987. Varieties *Osmo, Esa, Barcota, Kimo* and *Patu* have been named for official trials in foreign countries.

Based on the pure stand trials the most promising protein peas for Finland are the lines Hja 51850, Hja 52005, Hja 52024 and Hja 52118. The lines Hja 51821 and Hja 52257 also have an extremely high seed and protein yield, but their long growing time will limit cultivation to the southernmost part of Finland.

The lines Hja 51821, Hja 51850, Hja 52024, Hja 52086, Hja 52092, Hja 52104, Hja 52128, Hja 52208 and the varieties Panu and Patu are considered the most promising when peas are to be cultivated in mixed stands.

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SELOSTUS

Proteiiniherneen ideotyypin jalostus Suomen olosuhteisiin

Simo Hovinen

Hankkijan kasvinjalostuslaitos

Tutkimuksen tarkoituksena on osoittaa Suomessa parhaiten viljelyyn sopeutuvan proteiinihernelajikkeen ominaisuudet lähinnä rehutuotantoa varten. Puhdasviljelyyn sopivan ja korsiviljan kanssa seoksena viljeltävän lajikkeen ominaisuudet selvitetään erikseen. Käyttäen laajaa jalostusaineistoa hyväksi valkuaispitoisuuden muuntelua ja jalostusmahdollisuuksia tutkitaan tukemaan valintatyössä tehtäviä ratkaisuja.

Tutkimusaineistona ovat lajikekokeet puhdasviljelynä kahdella typpitasolla seitsemältä vuodelta ja lajikekokeet seosviljelynä pelkällä PK-lannoituksella kolmelta vuodelta. Pedigreemenetelmän mukaan valitun jalostusaineiston linjarivi- ja lisäysruutusadot ovat valkuaispitoisuusjalostuksen havaintoaineistona.

Tutkimuksen keskeisiä tavoitteita on selvittää geenin *af* vaikutus herneen eri ominaisuuksiin. Geeni aiheuttaa herneen lehdettömyyden. Havaintotyö tehtiin normaalitiheyksisistä kasvustoista, ei harvakseen kasvaneista yksilöistä.

Tämä työ on osa jatkuvaa jalostusohjelmaa lajikkeiden tuottamiseksi.

Valkuaisherneen ideotyyppi puhdasviljelyä varten

Geeni *af* aiheuttaa afila-ominaisuuden, jossa kaikki lehdykät ovat muuttuneet kärhiksi, mutta korvakkeet ovat normaalikokoiset. Tällaisia lajikkeita sanotaan puolilehdettömiksi eli afila-herneiksi. Liian suurten korvakkeiden katsotaan lisäävän lakoontumisalttiutta, toisaalta liian pienet korvakkeet (geeni *st*, ns. Filby-tyypissä) pienentää satoisuutta. Korvakkeiden puoliskon sopiva leveys on 30—35 mm ja pituus 60—70 mm. Koska satoisimmat ja samalla parhaiten pystyssä pysyvät jalostuslinjat ovat afilaherneitä, jalostustyö suunnataan lähes kokonaan tähän lehtityyppiin. Kaikki lehdelliset lajikkeet ovat liian herkkiä lakoontumaan. Hernelajikkeen Suomea varten tulee olla afila-tyyppiä.

Viljelyoloihin sopeutuneiden lajikkeiden varren nivelluku on 13—16, joista 3—5 on palkoa kantavia. Satoisimpien lajikkeiden varrenpituus on 61—94 cm johon puhdasviljelylajikkeiden varrenpituuden tulee sijoittua. Afila-herneiden varren tyvi on yleensä ohuempi kuin lehdellisten. Kasvuston kärhien runsaus pienentää lakoontumisherkkyyttä niin voimakkaasti, että varren paksuuserojen mahdollinen vaikutus peittyy.

Eräiden lyhytvartisten lajikkeiden satoindeksi on jopa 60 prosenttia. Ne eivät ole satoisimpia. Toisaalta kovin pieni satoindeksi viittaa sopeutumattomuuteen. Optimisatoindeksi on 54—58 prosenttia.

Afila-herneet lakoontuvat generatiivisessa kasvuvaiheessa vähemmän kuin lehdelliset herneet. Varhaislako kukinnan lopulla pienentää lehdellisten lajikkeiden satoisuutta monessa tapauksessa, samoin paha lakoisuus tuleentuneena johtuen korjuutappioista. Myös kaikki afilalajikkeet saattavat lakoontua juuri ennen tuleentumista. Varren jäykkyyden parantaminen on seuraava jalostustavoite. Riittävän viljelyvarmuuden saavuttamiseksi lajikkeen keskimääräinen lakoisuus ei saa ylittää 30 prosenttia.

Useiden afila-herneiden juuristo on pienempi kuin lehdellisten herneiden. Myös *Rhizobium*-nystyröiden luku ja juuriston typpimäärä on pienempi. Afila-lajikkeiden välillä on kuitenkin eroja näissä ominaisuuksissa. Juuristo-ominaisuuksien vaikutus satoon on epäselvä. Hernelajikkeen pitää pystyä tehokkaaseen symbioosiin *Rhizobium*-bakteerien kanssa tuottaakseen korkeita satoja ilman typpilannoitusta. Hernelajikkeilla tulee olla niin vahva resistenssi erityisesti *Ascochyta* sp. ja *Peronospora* sp. kasvitauteja vastaan, ettei kemiallista torjuntaa tarvita.

Liian suuri siemenkoko pienentää siemenlukua palossa. Satoisimpien lajikkeiden palkojen siemenluku on 6—9. Siemenkoon yläraja on tuhannen siemenen paino 270 g. Proteiinihernelajikkeen tulee olla valkokukkainen, siemenväri voi olla keltainen tai valkoinen. Siementen tulee olla pyöreitä. Valkuaispitoisuuden tulisi ylittää 23 prosenttia mikäli mahdollista.

Riittävän aikainen tuleentuminen huomioiden hernelajikkeen sopivin kasvuaika on 91—101 päivää, 1.—2. vyöhykettä pohjoisempana vieläkin lyhyempi. Satoisuuden varmistamiseksi kukinnan tulee kestää 19—28 päivää.

Hernelajikkeiden keskisato kokeissa on 4500 kg/ha, mikä on 75—90 prosenttia samoissa oloissa viljellyn ohran sadosta. Herneen valkuaissato on 990 kg/ha. Uusien hernelajikkeiden tulee ylittää nämä sadot merkitsevästi.

Valkuaisherneen ideotyyppi seosviljelyä varten

Seosviljelyä varten soveliaimmat lajikkeet poikkeavat eräiltä ominaisuuksiltaan parhaista puhdasviljelylajikkeista. Erityisen tärkeä tutkimuksen tulos on, että afilaherneet sopivat myös seosviljelyyn lehdellisiä lajikkeita paremmin. Hernelajikkeiden tulee olla taimettumisen jälkeen nopeakasvuisia kyetäkseen kilpailemaan hyvin korsiviljan kanssa. Sopivin kasvuaika on sama kuin puhdasviljelyssä, 91—101 päivää. Seosviljelyherneiden tulee olla pitempikasvuisia kuin puhdasviljelylajikkeiden, sopivin varrenpituus on 80—100 cm. Hyvä seosviljelylajike muodostaa jo harvan tukiviljan kanssa lähes lakoontumattoman kasvuston. Koska hyvin pieni siemenkoko on epäedullinen taimien kilpailukyvyn kannalta korsiviljan oraiden kanssa, tulee herneen tuhannen siemenen paino olla 200—270 g.

Seosviljelyherneen biologisen typensidontakyvyn tulee olla niin tehokas, ettei seosviljelystä harvan tukiviljan kanssa tarvitse typpilannoittaa. Hernelajikkeiden tulee olla valkokukkaisia, pyöreäsiemenisiä ja siemenväriltään keltaisia tai vihreitä. Valkuaispitoisuuden tulisi olla yli 23 prosenttia, mikäli mahdollista.

Koetulosten mukaan seosviljelyn kokonaissato on 4700 kg/ha ja valkuaissato 900 kg/ha. Uusien lajikkeiden satoisuuden seosviljelyssä tulee ylittää nämä keskisadot merkitsevästi.

Valkuaispitoisuuden jalostus

Raakavalkuaispitoisuus on lajiketyypillinen ominaisuus, vaikka ympäristö vaikuttaa siihen voimakkaasti. Valikoimattoman linja-aineiston valkuaispitoisuuden vaihtelualue on 15.4—27.6 prosenttia. Vaihtelu on riittävän suuri tehokasta valintaa varten. Jalostusaineiston valkuaispitoisuutta voidaan ja pitää asteittain parantaa hylkäämällä valkuaispitoisuudeltaan heikot linjat jalostuksen kuluessa.

Eri risteytysalkuperien välillä on merkitseviä eroja valkuaispitoisuudessa. Valkuaispitoisuudeltaan parhaista risteytyspopulaatioista on kannattavaa tehdä uusittu laaja yksilövalinta.

Satoisuuden ja valkuaispitoisuuden välinen negatiivinen korrelaatio on niin heikko ($r = -0.19^{**}$), että suurisatoinen lajike voi olla hyvä myös valkuaispitoisuudeltaan. Valkuaissadon määrä on eniten riippuvainen siemensadon määrästä, vähemmän mutta merkitsevästi myös valkuaispitoisuudesta. Valkuaissadoltaan parhaiden lajikkeiden valkuaispitoisuus on 23—27 prosenttia.

Jalostuksessa valkuaispitoisuutta ei voida tarkastella irrallisena ominaisuutena. Valinnassa on otettava huomioon jalostuslinjan muut ominaisuudet, esimerkiksi aikaisuus. Aikaisten lajikkeiden valkuaispitoisuus on yleensä alhainen, samoin afila-herneiden verrattuna lehdellisiin lajikkeisiin. Näiden ominaisuusluokkien sisällä on riittävästi muuntelua valintaa varten. Koepaikan *Rhizobium*-kannan ja hernelajikkeen yhteensopivuus saattaa olla heikko vaikuttaen sadon valkuaispitoisuuteen saakka. Senvuoksi on tärkeää saada valkuaispitoisuustuloksia jalostuslinjasta usealta koepaikalta ilman typpilannoitusta.

Herneen typpilannoituksen tarve

Runsaasti, 80 kg/ha typpilannoitettu herne ei ole satoisampi kuin vain 16 kg/ha typpilannoitettu herne. Sensijaan typpilannoitus parantaa herneen valkuaispitoisuutta ja hiukan valkuaissatoa. Valkuaissadon kasvu on liian pieni, että biologisen typensidonnan korvaaminen typpilannoituksella olisi perusteltua.

Jalostusohjelman tuloksia

Jalostuksen tuloksena on saatettu markkinoille nimellisiä lajikkeita. Lehdelliset lajikkeet Hankkijan Hemmo ja Hankkijan Heikka sekä afila-herneet Hankkijan Tammi, Helka, Pika ja Panu on laskettu kauppaan Suomessa. Helka on suositeltavien lajikkeiden luettelossa Englannissa 1987 alkaen. Lajikkeet Osmo, Esa, Barcota, Kimo ja Patu on nimetty ulkomaiden virallisia kokeita varten.

Puhdasviljelykokeiden perusteella lupaavimmat valkuaishernelajikkeet Suomea varten ovat linjat Hja 51850, Hja 52005, Hja 52024 ja Hja 52118. Linjat Hja 51821 ja Hja 52257 tuottavat suuren siemen- ja valkuaissadon, mutta ovat myöhäisiä.

Seosviljelyä varten lupaavimmat linjat ovat Hja 51821, Hja 51850, Hja 52024, Hja 52086, Hja 52092, Hja 52104, Hja 52128 ja Hja 52208, myös lajikkeet Panu ja Patu.