# THE QUINOA PROJECT

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## Introduction

In the last two decades, new crops like oilseed-crops, fibre crops and aromatic crops/herbs received much attention in arable husbandry in Western-Europe. The interest for quinoa (*Chenopodium quinoa Willd.*) started 10 years ago, first of all for its nutritive value and more recently for potential industrial processing of its starch. Due to a high protein content and a high energy value, quinoa is highly appreciated in human and animal nutrition. Traditionally, quinoa grains are toasted or ground into flour. They can also be boiled like rice, and added to soups, or made into breakfast food or pasta. Foliage of quinoa can be used in the young leafy growth stage as a vegetable crop like spinach and in a later growth stage as a green fodder crop for animals, or to make into silage. The crop can also be dried and processed for green pellets.

Recently, there has been an increasing interest for quinoa in the food and processing industry. The properties of quinoa are highly suitable for alternative, vegetarian and baby food. The quality of starch granules offers quinoa opportunities as a fat-replacing ingredient in many diet products and as an interesting raw material for industrial processing. Although the perspectives look rather promising, the use of quinoa is still in an experimental stage of development.

Quinoa can be incorporated into arable husbandry, probably in an easy way. However, the yield level is still rather low and, for reasons of profitability, this can be a bottleneck for marketing quinoa as a competitive raw material for human food, for animal feed or for industrial purposes. In productivity, quinoa lagged considerably behind the high-yielding small cereals; therefore, the yield of quinoa needs to be improved by plant breeding and better crop management.

**In this booklet, information about the growth and development of quinoa has been gathered. Field experiences, results of experiments from the present EU-project (*AIR PROJECT 931426*) and data from literature have been used to provide guidelines of growing quinoa under the temperate climatic conditions of north-western Europe, up to the present day.**

## Taxonomy, origin and distribution

Quinoa (*Chenopodium quinoa*) belongs to the large genus of Chenopodium (about 250 species), but only three of them are cultivated, and only quinoa makes a significant contribution to local food or fodder production. The basic chromosome number of quinoa is $x = 9$; $2n = 4x = 36$. Originally, quinoa is a short-day plant, but many types flower and set seed in long-day environments.

Quinoa, also known as Peruvian rice or Inca rice, was largely naturalised in the mountainous tropical districts of the Andes in South America. It is likely, that quinoa was domesticated by the Pre-Inca-indians about 3000 to 5000 years ago at the altiplano plateau around Lake Titicaca in Peru. Quinoa is widely grown at altitudes between 2000 and 4000 m. In subtropical and temperate regions of central Chile quinoa types are also cultivated at sea level.

Quinoa has been introduced and tested in many regions outside its original home in the Andean area. Especially in cereal crop rotations quinoa can be grown as an additional break crop to control weed and disease problems that arise from the continuous cultivation of cereals. Up to now, in NW-Europe quinoa is still a new crop and grown on a (very) small scale but for many special purposes, ranging from food products to animal feed.

## Seed properties

Seed size and seed weight are largely dependent upon variety. Quinoa seeds are rather small and vary from 1.8 to 2.6 mm in diameter and from 1.5 to 6 mg in seed weight. In NW-Europe, seeds are relatively small and 1000-seed weight usually ranges from 1.5 to 3 g. The high nutritive value of quinoa is clearly demonstrated by a high energy content and a favourable chemical composition as is shown in **Table 1**. On dry matter base, the energy value is around 1500 kJ/100 g edible portion and similar to that of wheat and rice. The protein content is clearly higher than in common cereals. Moreover, the protein fraction is high in the essential amino acids lysine and methionine + cystine. The quinoa protein lacks gluten which makes quinoa very important for gluten allergic people. The starch content of the seeds is about 60%. Starch granules are uniformly small in size (1 to 4 µm) and make quinoa starch different from other plant species. The starch contains up to 20% amylose ; the fat content is largely composed by unsaturated lipid acids.

**Table 1. Composition of whole grains of quinoa and wheat (in %)[1]**

| | quinoa | wheat |
|---|---|---|
| Moisture | 12 | 15 |
| Carbohydrate | 55.7 | 66.8 |
| Protein | 13.0 | 8.9 |
| Fat | 5.3 | 2.2 |
| Fibre | 4.9 | 2.1 |
| Ash | 3.0 | 1.5 |

[1] after: Galwey (1993)

The seed coat (or pericarp) of the grains contains saponines, soap-like components which foam when dissolved in water. Saponines reduce palatability due to their bitterness, and are toxic if they reach the bloodstream. They are usually removed by vigorous washing or by abrasion of the seeds. The content of saponines varies from almost zero in saponine-free cultivars to about 4% in bitter cultivars.

## Quinoa as a green fodder crop

After emergence quinoa is growing very quickly, producing a lot of leafy biomass that can be used as roughage for cattle and sheep. Therefore, quinoa has been tested as a potential green fodder crop in Denmark. If harvested around the flowering stage, the biomass was relatively high in protein and low in crude fibre, and consequently favourable for animal nutrition. No clear differences in chemical composition and digestibility were found in the period from 2 weeks before until 2 weeks after flowering. So, for reasons of biomass yield the best time of harvest will be the post-flowering stage.

The fresh material can be used for direct feeding, but is more likely to process the fresh material for storage during longer times. Most economically, this can be done by ensiling. For making high quality silage the plant material must be cut into pieces less than 7 mm long and stored in airtight or traditonal silos. More recently, favourable experiences were obtained when the whole quinoa crop was used as a drum dried crop for animal feed. The nutritive value is similar to that of silage, but the palatability is improved because of a reduction of saponins during the drying process.

In practice, quinoa grown as fodder crop has to compete with common crops like grass and alfalfa. By using relevant Danish production data these three crops have been compared and some quantitative parameters are presented in **Table 2**.

**Table 2. Composition (in g/kg) of organic compounds and digestibility of drum dried whole crop quinoa, grass and alfalfa**

| Drum dried feed | Crude protein | Crude fibre | Digestible organic matter | Digestible crode protein | Digestible energy[1] |
|---|---|---|---|---|---|
| | | | | | |
| Quinoa | 195 | 279 | 626 | 145 | 12.1 |
| Grass | 187-198 | 291-358 | 600-700 | 120-130 | 11.6-13.5 |
| Alfalfa | 212-223 | 291-335 | 600-680 | 149-159 | 12.0-13.4 |

[1] in MJ/kg

## Development and growth

Quinoa is an annual plant species, sown in April/May and harvested in September/October. In temperate regions, the growth cycle ranges from 120 to 160 days depending on growing conditions and cultivar (short-day to neutral-day types).

Quinoa needs a fine and warm seedbed for optimal germination. Below soil temperatures of 10 °C, germination is very slow and uneven. Seedlings will emerge within one week at an average air temperature above 15°C. One week later the first two leaves appear and stem starts growing. Plant height depends upon varieties and can range from 0.5 to 3.0 m at maturity. In contemporary genotypes, tillering is rather poor and only found in low plant densities. The inflorescence, developing at the top of the stem, looks like a panicle, having a principal axis from which secondary axes originate, compact or lax, 15 - 70 cm long. The seeds are covered by a pericarp and susceptible to pre-sprouting.

Early, daylength-neutral cultivars may take 50-70 days to flowering and 90-120 days to maturity; late, short-day cultivars need 4-5 weeks more. Flowering within the panicle is irregular, resulting in non-synchronous ripening.

Quinoa forms a tap root from which secondary and tertiary roots develop. This large and highly ramified root system can exploit the upper soil layers intensively; some roots will penetrate into the soil to more than 1.5 m depth.

The development of quinoa can be characterised in several phenological growth stages. In **Table 3** a decimal code is presented for the determination of developmental plant stages.

During the growing season quinoa shows maximum productivity only for a short period before anthesis, when leaf area is highest. At the onset of flowering crop dry matter yield amounts to 4 to 6 tons per hectare. After flowering leaves start dying, reducing the leaf area, and consequently, the interception of light. Due to the decreasing photosynthetic rate and the loss of leaves, total aerial dry matter yield of a well-developed quinoa crop usually does not exceed 8 to 10 tons per hectare at harvest time, which is considerably lower than the production of spring cereals. Moreover, a relatively low proportion of above-ground dry matter is stored in the seeds; this so-called harvest index (HI) ranges from 30 to 50%. Consequently, the seed yield level of quinoa is rather low.

**Table 3. A decimal code for determination of developmental plant stages**

| Stage group | Main description | Decimal code | Specified description |
|---|---|---|---|
| 0 | Germination | 0.1 | Initial germination |
| | | 0.9 | Germination completed |
| 1 | Emergence | 1.1 | Initial emergence |
| | | 1.3 | 25% of plants emerged |
| | | 1.5 | 50% of plants emerged |
| | | 1.7 | 75% of plants emerged |
| | | 1.9 | Emergence almost completed |
| 2 | Vegetative development | 2.0 | First real leaves just visible |
| | | 2.1 | 1st pair of real leaves unfolded |
| | | 2.3 | 3rd pair of real leaves unfolded |
| | | 2.5 | 5th pair of real leaves unfolded |
| | | 2.7 | 7th pair of real leaves unfolded |
| | | 2.9 | 9th pair of real leaves unfolded |
| 3 | Inflorescence development | 3.0 | Flower buds detectable |
| | | 3.1 | Flower buds just visible |
| | | 3.3 | Flower buds 0.5 cm |
| | | 3.5 | Flower buds 1.0 cm |
| | | 3.7 | Flower buds begin pyramid |
| | | 3.9 | Flower buds distinct pyramid |
| 4 | Initial flowering | 4.1 | First glomeruli show anthers |
| | | 4.3 | 25% of glomeruli show anthers |
| | | 4.5 | 50% of glomeruli show anthers |
| | | 4.7 | 75% of glomeruli show anthers |
| | | 4.9 | Full bloom |
| 5 | Deflowering | 5.1 | Anthers of first glomeruli wilted |
| | | 5.3 | 25% of glomuruli show wilted anthers |
| | | 5.5 | 50% of glomuruli show wilted anthers |
| | | 5.7 | 75% of glomuruli show wilted anthers |
| | | 5.9 | Almost all anthers wilted |
| 6 | Seed filling/panicle coloration | 6.0 | Seeds watery ripe\panicle green |
| | | 6.1 | Seeds milky ripe\initial panicle coloration |
| | | 6.3 | 25% panicle coloration |
| | | 6.5 | Seeds dough ripe\50% panicle coloration |
| | | 6.7 | 75% panicle coloration |
| | | 6.9 | Seeds physiological ripe\panicle full color |
| 7 | Panicles ripening | 7.1 | Initial decoloration of panicles |
| | | 7.3 | Panicles 25% decolored |
| | | 7.5 | Panicles 50% decolored |
| | | 7.7 | Panicles 75% decolored |
| | | 7.9 | Panicles almost wilted |
| 8 | Leaf senescence or wilting | 8.1 | Initial leaf senescence or wilting |
| | | 8.3 | 25% of leaves senesced or wilted |
| | | 8.5 | 50% of leaves senesced or wilted |
| | | 8.7 | 75% of leaves senesced or wilted |
| | | 8.9 | Almost all leaves senesced or wilted |
| 9 | Stem ripening | 9.1 | Initial yellowing of the stems |
| | | 9.3 | 25% of stems turned pale yellow |
| | | 9.5 | 50% of stems turned pale yellow |
| | | 9.7 | 75% of stems turned pale yellow |
| | | 9.9 | Stems almost completely discolored |

Seed yield of a quinoa is determined by the number of grains per unit area (i.e. panicle number multiplied by the number of seeds per panicle) and grain weight. In NW-Europe, where a quinoa crop usually consists of plants with one single stem, the seed yield per unit area can be given by the formula :

seed yield ($g/m^2$) = plants/$m^2$ x seed number/panicle x mean seed weight (g)

or simplified:

*seed yield ($g/m^2$) = number of seeds per $m^2$ x mean seed weight (g)*

All three yield components may vary considerably, but they are interdependent. Due to this, a quinoa crop has a strong compensatory ability, especially in the number of seeds per panicle. To give an understanding of the yield components of quinoa, data are presented in **Table 4**.

**Table 4. A guide of the production pattern of quinoa**

| | Normal | Variation |
|---|---|---|
| number of plants or panicles/$m^2$ | 100 | 25 - 300 |
| number of seeds/panicle | 1500 | 500 - 10000 |
| number of seeds/$m^2$ | 150000 | 50000 - 250000 |
| 1000-seed weight (g) | 2 | 1.5 - 3 |
| seed yield (kg/ha) | 3000 | 1000 - 5000 |

Although a very low density of 25 plants per $m^2$ is able to achieve similar seed yields, the crop stand is very uneven and open and so, the competition against weeds is poor.

## Ecology

Quinoa is adapted to grow under different climate conditions and on different soil types ranging in acidity from pH 6 to 8,5. It tolerates soils that are infertile or moderately saline. Even on sandy and on peat soils with a pH of 5 quinoa turned out to grow well.

High temperatures are favourable for germination; about 10 °C seemed to be minimal for proper germination. Quinoa seeds are small and need to be drilled superficially, 1 to 2 cm deep. For good germination and emergence, quinoa seeds need a well-prepared seedbed with a sufficient moisture and air content. Under such conditions emergence rates well over 50% can be realised. However, sub-optimal or unfavourable conditions like drought or waterlogging, hamper germination and reduce emergence to unpredictably low rates. Moreover, on a very heavy clay soil the preparation of a fine-textured seedbed is problematic, and often low emergence rates are found.

From the seedling stage onwards, quinoa is a an easy crop to grow. Quinoa withstands very light night frost but is sensitive to temperatures below -3°C, depending on the variety and growth stage. During early growth stages quinoa requires sufficient rainfall, but is rather drought tolerant during later growth stages. Especially at the end of the ripening period the crop becomes very sensitive to rainfall, because the seeds of some varieties are not dormant and are subject to premature sprouting.

The demand for minerals is rather low, but will largely depend on crop yield. Nitrogen, phosphorus

**Table 5. Content and uptake of N, P and K at the onset of grain-filling and at harvest (seed yield about 4 t/ha).**

| | Start of seed filling | Harvest time | | |
|---|---|---|---|---|
| *Nitrogen:* | | seeds | straw + chaff | Total |
| contents (g/kg) | 15 | 21 | 4 | |
| uptake (kg N/ha) | 100 | 75 | 20 | 95 |
| *Phosphorus* | | | | |
| contents (g/kg) | 5 | 5.5 | 1.5 | |
| uptake (kg P/ha) | 30 | 20 | 7 | 27 |
| *Potassium:* | | | | |
| contents (g/kg) | 60 | 15 | 26 | |
| uptake kg K/ha) | 400 | 55 | 130 | 185 |

and potassium are the major elements, and a supply of these minerals can improve the seed yield considerably. In **Table 5** some experimental data about the contents and uptake for N, P and K at the start of grain-filling and at harvest are presented for a quinoa crop yielding about 4 tons of seed per hectare. At the onset of grain growth uptake of N, P and K was maximal. Afterwards, the quantities of nitrogen and phosphorous were rather stable in the plant, but were largely translocated to the seeds. Potassium clearly decreased, due to foliage losses and leaching. At harvest time most K is found in the stalks; very high K-contents were measured in chaff (up to 80 g K/kg dry matter).

In the present EU-project it is found that nitrogen is the major limiting factor for seed and dry matter yield, when spring temperatures are low and when quinoa has developed a poor root system, for example on heavy clay soils.

## Crop management/husbandry

***Soil and seedbed preparation***

A good rooting system is prerequisite in view of crop development and crop productivity. After the harvest of the previous crop the soil will be tilled in such a way, that the waterholding capacity and aeration are as good as possible. Especially in early growth stages, water needs to be available for good root growth. Then, large and ramified roots will be built up, that fasten the plant strongly in the soil and will take care of a sufficient uptake of water and minerals.

Due to their small size, seeds must be sown superficially at 1 to 2 cm. The seeds must make contact with moist soil particles for germination. Germination will largely fail in dry soils. For emergence the top layer can get away with not being compact, but for germination the sub-top layer must be firm in order to provide moisture. The seedbed must be flat, with a homogenous top layer in which the seeds can be drilled superficially. Especially on very heavy clay soils, it is difficult to create a good seedbed and favourable conditions for germination as well as emergence. Moreover, a rapid emergence of the seeds reduces plant losses due to soil pathogens like *Pythium spp.* and makes the crop competitive against weeds.

***Cultivars***

Since the last three decades breeding research started in quinoa, and now some cultivars have been placed on national variety lists or are commercially sold. The variety Sandoval is grown in the United Kingdom. In the Netherlands, the cultivar Carmen is registered and may enter the variety list in short time. In Denmark, the cultivar Olav can be grown for producing green fodder, as well as for seed production. In the north-western European countries, very late flowering cultivars can not produce good seed yields. A selection of combi-types has solved this problem. A representative of such a combi-type is the above-mentioned Danish variety Olav. To avoid poor weather conditions at the rather late harvest time, early ripening varieties must preferably be used for seed production.

**Based on field experiences, the ideal type of a quinoa cultivar is characterised by:**

- early and homogeneous ripening
- short and stiff straw
- a high harvest index
- resistant to seed loss and pre-sprouting
- free of saponins
- resistant to diseases and pests

*Seed*

Quinoa seed is small, but usually germinates well in laboratory tests. Under field conditions emergence rate varies widely from less than 20% to well over 60%. Although soil and weather conditions prevail, well-viable, high quality seeds need to be sown to improve seedling emergence and good crop stand. Differences of seed quality between varieties are often unclear, but may be related to harvest conditions. Within each variety, emergence is favoured by larger seeds. Therefore, in seed lots the small seeds must preferably be sifted out. Although information is scarce, seed treatment appeared to have little influence on emergence. More research is needed on how to improve seedlings establishment in the field under different growing conditions.

***Sowing time, seed rate and row width***

For a quick germination, emergence and seedling growth, soil temperatures should be higher than 10 °C. Therefore the optimal sowing time will vary from mid-April in southern regions to mid-May in northern regions of NW-Europe. Early sowing at low temperatures retards germination, decreases emergence and is unfavourable for seedling and early plant growth. In field experiments, advanced sowing has not resulted in an earlier harvest time nor in a higher seed yield.

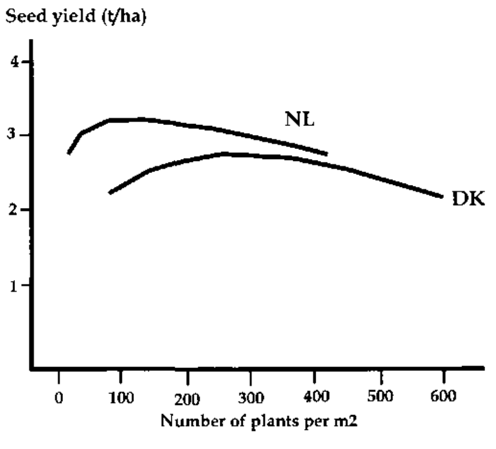


**Figure 1. Seed yield of quinoa at increasing plant densities. Means of a number of experiments in Denmark (DK) and The Netherlands (NL).**

Emergence rate has been difficult to predict and varies widely under field conditions. This uncertainty is an obstacle in getting the right number of plants per $m^2$. High yields can be achieved at a wide range of plant densities, in the Netherlands from 30 to more than 250 plants per $m^2$, in Denmark from 200 to 450 plants per $m^2$ (**Figure 1**). Because of weed suppression, synchronous ripening, harvestability and yield safety in practical production, approximately 100 plants per $m^2$ (in the Netherlands) and 100 to 150 plants per $m^2$ (in Denmark) must be recommended. For realising a plant density of 100 plants per $m^2$ and an emergence rate of 40%, about 250 seeds need to be sown per $m^2$, corresponding to a seed rate of 6 kg/ha. Depending upon 1000-seed weight, soil and weather conditions seed rate may vary from 4 to 8 kg/ha to be sure to achieve a plant number of 50 to 150 per $m^2$.

Row distances appeared to have little influence on seed yield (**Table 6**). Although soil covering and light interception by the crop decreased especially during the early growth, no differences in yield could be measured, when row distance increased from 12.5 to 50 cm; even at 75 cm row width, seed yield was hardly lower.

**Table 6. Seed yields of quinoa (t/ha), grown at row distances of 12.5, 25, 37.5, 50 en 75 cm at 3 locations**

| Row distance (cm) | 12.5 | 25 | 37.5 | 50 | 75 |
|---|---|---|---|---|---|
| Location | | | | | |
| Roskilde, DK 1990 | 3.01 | 2.93 | | 3.22 | |
| Lelystad, NL 1995 | 3.14 | 3.02 | 3.14 | 3.20 | 3.20 |
| Lelystad, NL 1996 | 3.74 | 3.67 | 3.82 | 3.90 | 3.75 |

***Fertiliser application***

As in most seed crops nitrogen, potassium, phosphorus and to a lesser degree magnesium, sulphur and calcium are found in considerable amounts in the seeds and vegetative organs of quinoa at harvest. Most experimental data are related to nitrogen dressing; probably, the other major and minor elements may be present in sufficient amounts in the soil and are often not applied as fertiliser.

*Nitrogen fertiliser*

As can be seen in **Table 5**, mean uptake of nitrogen by a quinoa crop producing a seed yield of 4 t/ha amounted to 100 kg N/ha. This indicates a demand of about 25 kg N per ton of seed produced.

In field experiments in Denmark and the Netherlands, the optimal application of nitrogen was found to be 100-160 kg N/ha (**Figure 2**). However, the N-response curves differed from site to site and from

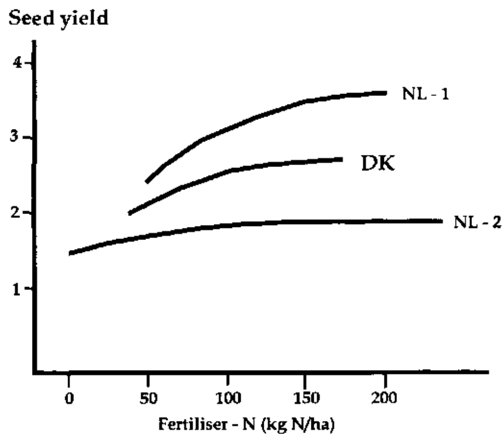


**Figure 2. Seed yield of quinoa at increasing nitrogen application rates. Data from Denmark (DK) and The Netherlands (NL-1: light clay, NL-2: heavy clay soil).**

year to year. The mineral N content in the soil amounting from 20 to 100 kg N/ha in early spring and the rate of N-mineralisation contributes largely to the N-supply and is thus a determining factor for the application of fertiliser-N. At a low application of 50 kg N/ha foliage mass, leaf area and light interception developed poorly, and consequently total dry matter yield and seed yield were lower. At 150 kg N/ha or more, neither crop growth nor seed yield were hardly affected. Consequently a supply of 100 to 150 kg N/ha is recommended.

Most of the nitrogen is taken up by the crop before flowering during the stages of leaf production. A single application at sowing has turned out to provide sufficient nitrogen for the crop growth and seed yield. If the seed yields of quinoa will increase considerably in the future, the demand for nitrogen will undoubtedly increase and consequently, more fertiliser-nitrogen is needed. It is likely that at high nitrogen dressings (more than 150 kg N/ha) a split application may be preferred in order to avoid high salt concentrations during germination and seedling stage.

For green fodder production a higher amount of nitrogen is needed. To obtain a high protein content and a high proportion of leaves in the whole crop biomass 300 kg N/ha should be applied twice: 100 kg N/ha at sowing, and 200 kg N/ha 5 weeks later.

It is not expected that the form of N-fertiliser will influence crop growth nor seed yield. Usually, nitrogen is applied as calciumammoniumnitrate.

*Phosphorus fertiliser*

About 30 kg P/ha, corresponding to 70 kg $P_2O_5$/ha has to be taken up by the crop before the onset of seed filling. In most arable soils such amount of phosphorus is available and a phosphate dressing is usually not necessary. If the phosphorus supply is deficient (low soil-P, P-fixing soils) the P demand needs to be covered by a water-soluble form of fertiliser-P. The amount of applied phosphorus is similar for seed and fodder production.

*Potassium fertiliser*

Quinoa has a high potassium requirement, especially for stem growth (see **Table 5**). At the end of flowering, more than 400 kg K/ha, corresponding to 500 kg $K_2O$/ha, will be taken up by a good quinoa crop. Although most arable soils are able to provide large amounts of potassium, additional potassium might be necessary. The amount of potassium to apply depends on previous crop and soil type and may vary from 100 to more than 200 kg K/ha. To avoid possible salt damage to the seedlings, a basic application of potassium may be given already some time before sowing quinoa.

*Microminerals*

Microminerals are used in very small quantities and are usually available in the soil in sufficient amounts. Among these minerals manganese seems to be most critical. Deficiency of manganese may first be expected in a dry spring on calcareous soils.

***Weed control***

Quinoa is a new crop and until now grown on a very small scale. At higher temperatures (above 15 °C) quinoa grows rapidly and is a strong competitor to weeds. However, if spring temperatures are rather low, weeds often develop well and may reduce seed yield and seed quality of quinoa, especially the tall-growing weeds like fat hen (*Chenopodium album*) and redshank (*Polygonum persicaria*). In many countries herbicides are not allowed in quinoa cultures and therefore, weed control need to be done mechanically or by hand weeding.

Recently, a number of herbicides were tested for possible use in quinoa. The reliability of these herbicides is restricted, because experimental data about effectiveness of weed control and phytotoxicity to quinoa are scarce, and moreover these effects are strongly affected by environmental conditions. Often, unacceptable crop damage occurred in experimental plots. Further research need to be done to confirm the findings and to improve the reliability if herbicides are allowed for practical use. In the

United Kingdom, metamitron + propyzamide, propizamide + propachlor, monochloracetate and fluazifop-P-butyl, in the Netherlands, lenacil, metamitron, chloridazon and triflusulfuron and in Denmark, propyzamid, fluazifop-P-butyl and reglone (before sowing) have been used **in experimental trials** with varying success.

Mechanical control of weeds in arable crops is usually done by harrowing, inter row cultivation and/or hoeing. Harrowing is most effective when the weed plants are still at the seedling stage. However, at that time the quinoa crop is also in a young growth stage and whole-field harrowing will cause severe plant losses. Therefore, harrowing and/or hoeing between the quinoa rows are the only options. For hoeing, row distances need to be at least 25 cm, preferably wider. Between the rows all weeds can be mechanically controlled, but within the rows, hand weeding is the only option. Also the earthen-up of the rows (in combination with hoeing) may be a possibility, especially when the weed plants are still small.

***Diseases and pests***

Under the temperate climate conditions of NW-Europe quinoa has shown so far to be tolerant to pests and diseases and significant seed losses are rather scarce.

*Diseases*

The susceptibility for most diseases is largely dependent on variety, but also on edaphic factors. Therefore the attack will vary considerably from year to year.

Among the fungal diseases which have been observed in quinoa fields in NW-Europe, the most important are root rot (*Pythium spp.*), gray mould (*Botrytis cinerea*), downy mildew (*Perenospora farinosa*) and seed rot (*Sclerotinia sclerotiorum*). Root rot occurs during seedling stage, mainly on very heavy clay soils. Especially when germination and emergence pass slowly (low temperatures), root rot is able to attack the seedlings resulting in considerable plant losses. Referring to gray mould , gray lesions of irregular shape occurs on the stems and on the inflorescences of mature plants. If the central axis of the inflorescence has been attacked, the secondary axes sometimes collapse and seed set as well as seed filling may be hampered. Attacks on quinoa by downy mildew cause yellowing and early senescence of the leaves. The susceptibility for most diseases is largely dependent on variety.

*Insects*

In literature a series of insects causing more or less damage to a quinoa crop are mentioned. However, in NW-Europe, only black bean aphids (*Aphis fabae*) have shown to attack the crop and multiply well by sucking on leaves and stems. These aphids appear during late spring and summer on some plants spread over the field. After a rapid multiplication, these plants will be occupied by a large number of aphids. Although some damage on seed yield must be expected, no clear experimental data are available concerning yield losses caused by this insect.

In 1996, a remarkable number of caterpillars belonging to the gamma moth (*Autographa gamma*) has been observed in quinoa. These green caterpillars reach to about 20 mm in length, destroy leaves and consequently reduce leaf area. In Denmark, control was strongly needed, otherwise the attack would have resulted in crop failure. Possible effects on seed yield are not known, but may be very drastic. Other insects observed in quinoa fields, like caterpillars of *Coleophoridae*-species and leaf miners, have not shown to cause significant damage to crop growth and seed yield in NW-Europe. On sandy soils, biting injury was found on young quinoa plants, probably caused by the beet flea-beetles (*Chaetocnema concinna* and *C. tibialis*) and (larvae of) the beet carrion beetle (*Aclypea apaca*). These insects were observed during dry and cloudy weather in spring in the Netherlands. The damage caused by these insects is not known.

*Nematodes and viruses*

Quinoa may be attacked by a number of soil-borne nematodes, but damaging effects of nematodes on yield have not been evaluated so far. However, growing quinoa in a crop rotation system its behaviour towards the maintenance and/or multiplication of nematodes is important for the culture of successive crops. In the Netherlands, quinoa has shown to be resistant to the sugar beet cyst nematode (*Heterodera schachtii*). Quinoa is a host for *Meloidogyne chitwoodi* (maize root knot nematode) and *Meloidogyne hapla*, but not for *Meloidogyne fallax*. The size of nematode infection is largely variety-dependent.

Although some mosaic viruses are known to the crop in Andean regions, there is no information about viruses in quinoa grown under the temperate climate of NW-Europe.

*Birds*

Birds attack quinoa seedlings and feed on the seeds in mature inflorescence. Birds are rather selective, and losses due to birds are said to be lower in saponin-rich, bitter varieties than in varieties with a low saponin content. Up to now, the damage by birds on large-scale quinoa fields in the open land appeared to be of little importance.

## Harvest and storage

In commercial fields quinoa is harvested by combine-harvester. The optimal time of harvesting is difficult to judge in some varieties due to the non-synchronous ripening of the seeds within the inflorescence. For choosing the best harvesting time, weather conditions, pre-sprouting, seed losses due to shattering and seed moisture content must be taken into account. Harvest can take place when the matured panicles feel dry by hand contact, and the seeds easily set free. Under temperate climatic conditions the moisture content of the seeds ranged from 15% to more than 20% at harvest.

In order to store quinoa for longer periods the moisture content needs to be about 12%, so artificial drying is necessary. Because quinoa seeds are small, air movement is restricted, and air ventilation needs to be done by bed drying in layers of limited height (0.75 to 1 m).

Drying of quinoa can be done in batches or in bed dryers by continuous or dis-continuous use of heated or unheated air depending upon outside temperature and humidity and upon the moisture content and the temperature of the seed lot. For quinoa no information is available about drying time and drying temperature. Drying will take at least some days to more than a week. According to cereals, critical maximum temperature should be about 50 °C for seed purposes and 60 °C for consumption purposes.

Moreover, the harvested product usually contains a considerable amount of impurities like flower and straw particles. If harvest takes place by a well-adapted combine harvester under favourable conditions the impurities can be kept below 5%, but seed cleaning is necessary.

For the food processing industry saponins are not or only tolerable to a very low content. For that reason the quinoa seeds need to be brushed to remove the seed coat in order to get rid of the saponins.

## Seed quality and marketing

As was shown in **Table 1**, quinoa seeds largely consist of starch and proteins. Therefore quinoa is very suitable for human consumption. The protein is high in the essential amino acids lysine and methionine+cystine, making it complementary to true cereals for lysine and to pulses for methionine and cystine. Because the good protein composition of quinoa approaches that of casein, quinoa can be used in baby-food.

The bottleneck for quinoa for consumption purposes is the presence of saponins, which are not wanted by the food processing industry. Saponins reduce palatability due to their bitterness and are toxic if they reach the bloodstream. Saponins are situated in the seed coat and can largely be removed by vigorous washing or by removing the seed coat by brushing.

Starch is stored in granules. The starch granules are uniform, but extremely small in size (2 to 4 μm). Due to this small size starch has a fatty taste and can replace fat in diet products.

Recently, the starch processing industry became interested in the small-sized and uniform starch granules of quinoa as a raw material for special outlets. However, for commercial starch processing the product prices must be rather low, and this makes a profitable production of quinoa unlikely at present for this purpose. However, if the yield of quinoa can be increased it may even be of interest to the starch industry.

## Gross margins

Quinoa is a new crop, and commercial growing is only done for specific purposes, mainly on a contract base. Clear data about production costs, product prices and subsidy regulations are missing and so, the gross margins of quinoa can only be given approximately. Market prices are not available, and some cultivation costs are difficult to assess. Chemically, control of weeds, diseases and pests is not allowed everywhere, and weeding might be more costly than in other crops.

Data about growing quinoa as an arable crop can be obtained from experimental work carried out in Denmark and the Netherlands. Although the growing technique of quinoa is almost the same in both countries, clear differences occur in input costs. Therefore, in **Table 6** the production costs have been mentioned for both countries separately. In this table, the costs for field operations on contractor's base have also been inserted. As can be seen in this table the production costs for quinoa were about 840 DG in the Netherlands and 2700 KK in Denmark, both according to about 400 ECU per hectare.

In an arable crop rotation quinoa will be an alternative for a cereal crop. Therefore, quinoa becomes interesting for the farmer, if its gross margin will be similar or higher than that of cereals. Although a comparison between cereals and quinoa is difficult to make due to uncertainties in subsidising support to cereals, it is quite clear that the price of quinoa must be considerably higher than that of winter wheat because of its low yield level. In the Netherlands, the farmer's price for quinoa seed must be at least 20 ct/kg (= 0.10 ecu/kg) higher than that of winter wheat.

**Table 6: Production costs of growing quinoa for seed production in The Netherlands and Denmark**

| | The Netherlands | | | Denmark | | |
|---|---|---|---|---|---|---|
| | amount per ha | costs (NG)[1] per unit | costs (NG) per ha | amount per ha | costs (DKK)[1] per unit | costs (DKK) per ha |
| | | | | | | |
| seed | 6 | 25 | 150 | 8 | 50 | 400 |
| Fertiliser: | | | | | | |
| N | 125 | 0.95 | 119 | 120 | 4.85 | 582 |
| P | 25 | 1.75 | 44 | 25 | 8.10 | 202 |
| K | 80 | 0.65 | 52 | 50 | 3.00 | 150 |
| Pesticides | | | | | | |
| pirimor | | - | | 0.3 | 400 | 120 |
| pyrethroids | | - | | 0.8 | 60 | 48 |
| Others | | | | | | |
| drying | 3000 | 0.10 | 300 | 3000 | 0.25 | 750 |
| cleaning | 3000 | 0.05 | 150 | 3000 | 0.125 | 375 |
| insurance/ interest | | | 25 | | | 75 |
| Sub-total costs | | | 840 | | | 2702 |
| | | | | | | |
| Machinery: | | | | | | |
| cultivating | 2 | 65 | 130 | 2 | 170 | 340 |
| ploughing | 1 | 286 | 286 | 1 | 600 | 600 |
| fertilising | 1 | 58 | 58 | 1 | 130 | 130 |
| harrowing | 2 | 45 | 90 | 1 | 300 | 300 |
| rolling | 1 | 35 | 35 | 1 | 160 | 160 |
| drilling | 1 | 150 | 150 | 1 | 275 | 275 |
| spraying | | | | 2 | 150 | 300 |
| threshing | 1 | 450 | 450 | 1 | 1600 | 1600 |
| Total costs | | | 2039 | | | 6407 |

[1] Costs in Dutch Guilders (2 DG = 1 ECU) or Danish Crowns (7 DKK = 1 ECU)

As a green fodder crop, quinoa will be in competition with grasses, alfalfa and other fodder crops. In **table 7** the production costs and product prices are presented for quinoa, grass and alfalfa, the latter two grown over three years. Under Danish growing conditions, dry matter yields amounted to 9.1 ton/ha for quinoa and alfalfa and to 11.1 ton/ha for grass. The price per Feed Unit for cattle ($FU_C$) of quinoa is similar to alfalfa and lower than grass, indicating quinoa being a potential fodder crop.

**Table 7. Production costs for growing quinoa, grass and alfalfa in Denmark**

| | | QUINOA | | GRASS | | ALFALFA | |
|---|---|---|---|---|---|---|---|
| treatment | price per unit | units per ha | costs [1] per ha | units per ha | costs [1] per ha | units per ha | costs [1] per ha |
| seeds | | 6 | 300 | 26 | 329 | 30 | 325 |
| nitrogen | 4.85 | 300 | 1455 | 400 | 1940 | 0 | 0 |
| phosphor | 8.10 | 25 | 202 | 40 | 324 | 40 | 324 |
| potassium | 3.00 | 50 | 150 | 250 | 750 | 250 | 750 |
| Production costs | | | 2107 | | 3343 | | 1399 |
| ploughing | 535 | 1 | 535 | 0.33 | 178 | 0.33 | 178 |
| harrowing | 90 | 2 | 180 | 0.33 | 60 | 0.33 | 60 |
| rolling | 140 | 1 | 140 | 0.33 | 46 | 0.33 | 46 |
| spraying | 173 | 2 | 346 | 0 | 0 | 1 | 173 |
| sowing | 230 | 1 | 230 | 0.33 | 76 | 0.33 | 76 |
| swathing | 240 | 1 | 240 | 5 | 1200 | 3 | 720 |
| silaging | 660 | 1 | 660 | 5 | 3300 | 3 | 1980 |
| cariage | 80 | 1 | 80 | 5 | 400 | 3 | 240 |
| Labour costs | | | 2411 | | 5260 | | 3473 |
| drying | 0.50 | 9100 | 4550 | 11100 | 5550 | 9100 | 4550 |
| Total costs | | | 9068 | | 14153 | | 9422 |
| int.price/kgdm incl drying | | | 1.00 | | 1.28 | | 1.04 |
| int.price/kgdm excl. drying | | | 0.50 | | 0.78 | | 0.54 |
| kg.pr. FUc | | | 1.67 | | 1.47 | | 1.57 |
| int. price/ FUc incl drying | | | 1.66 | | 1.87 | | 1.63 |

[1] prices in DKK (7 DKK = 1 ECU)

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