GROWING QUINOA IN WASHINGTON STATE

Introduction

Quinoa (*Chenopodium quinoa* Willd.) is gaining popularity as a relatively new crop for Washington State. It has been cultivated for thousands of years around its center of origin in South America, but recently has gained worldwide recognition for its nutritional benefits and adaptability to a variety of environments.

Quinoa (Figure 1) is an annual broadleaf crop in the Amaranthaceae family; other notable crops in this family of plants include spinach and beets. Quinoa, however, is grown primarily for its edible seeds (Figure 2), which have been touted as a "superfood" thanks to their high nutritional value. It is also known for being a complete and balanced source of protein, rich in lipids and essential fatty acids, as well as having higher vitamins and minerals than cereal grains. Additionally, quinoa does not contain gluten.

Quinoa production in North America was very limited until recently. Increased consumer demand along with agronomic benefits has raised interest for producers. Quinoa has been successfully cultivated in regions such as the Canadian prairies, the San Luis Valley of Colorado, coastal areas in central California, Willamette Valley of Oregon, and the Olympic Peninsula in Washington. Other areas of Washington State could also provide the right climate and conditions for producing quinoa, such as the maritime climates found along much of the western region, the mountainous regions in central and northern areas of the state, and the Palouse River Basin on the eastern edge.

Quinoa may be a suitable crop for a variety of cropping systems that can be found in Washington State. Given its history as a health food, the demand for organic quinoa is especially high; in the United States at the peak demand in 2015, over 65% of quinoa purchased was organic (Nuñez de Arco 2015). Early production in U.S. agriculture was also largely organically managed, as there were no chemicals approved with tolerances for quinoa, and much of the early variety selection and adaptation occurred under organic management. Quinoa is known for producing quality yields even in adverse conditions, including low fertility, throughout the world. For any system, quinoa can be a beneficial rotation crop to help break cereal disease cycles, and even the conventional market value is high compared to similar crop types.

Figure 1. Quinoa plants near Pullman, Washington, in July 2015. Photo: Rachel Wieme.

Figure 2. The small, disk-like, edible seeds of quinoa (top photo), which are usually cooked similarly to boiled rice. Seed color can vary from white to yellow, brown, red, gray, or black (bottom photo); this is a small selection of quinoa diversity from around the world. Photos: Rachel Wieme.

Environment and Variety Selection

From its high elevation origins in the Andes Mountains of South America, quinoa is relatively tolerant to cold temperatures and light frost. Early trials of quinoa in North America revealed that areas with cool summers, especially cool summer nights, are most suitable for quinoa production; trials in areas where temperatures exceeded 95□F often failed to set seed. It was suspected that high temperatures caused pollen sterility and plant dormancy (Johnson and Croissant 1985; Johnson 1990).

Quinoa can grow in a variety of soil types ranging from coarse sand to heavy clay, but good drainage is important as waterlogging can cause stunting and damping off (González et al. 2009). Quinoa is known for being tolerant to a wide range of adverse conditions: it can be grown in soils with pH ranging from 4.5 to 9, in climates prone to drought, and in areas of low fertility. Additionally, it is known as one of the most salt-tolerant crops, being a good option for saline-affected soils. However, the key to this wide range of tolerance for quinoa is appropriate utilization of available genetic diversity. Hundreds of quinoa varieties are cultivated in South America which possess traits that help it thrive under various challenging conditions. For example, certain varieties are more tolerant to drought or salt, while other varieties are optimally adapted to maritime climates, just as some perform better in loamy or clay loam soil compared to sandy soil. Therefore, proper variety selection is critical for quinoa to be successful in Washington climates.

Quinoa varieties for Washington need to be day-neutral or require long days to induce flowering and seed production (varieties originating closer to the equator generally require short days). Current growing periods range from 80 to 150 days, depending on the variety, and the earlier-maturing varieties can be beneficial for avoiding some of the Washington-specific challenges that are listed below (Figure 3).

Variety trials in western and eastern Washington are ongoing to determine and develop best-suited varieties for these growing regions (Figure 4). Each of these regions has distinct climatic challenges for quinoa that must be overcome for quinoa production to expand. In western Washington, late summer and early autumn rains can cause preharvest sprouting (moisture causing the seed to germinate while still on the panicle), mold, or plant lodging, all of which can cause partial or complete yield losses. Look for varieties that are described as preharvest sprout resistant, fast-maturing, and shorter in stature to help avoid some of these issues. For eastern Washington, higher summer temperatures combined with low relative humidity can cause quinoa pollen sterility and failure to set seed, so varieties that are heat tolerant in dry conditions are essential.

Figure 3. Differences in maturity among quinoa varieties: variety ‘Titicaca’ (foreground) contrasted with an experimental line at the WSU Northwestern Research and Extension Center near Mount Vernon, Washington, in August 2018. Photo: Daniel Packer.

Figure 4. Variety trials of quinoa growing at WSU Cook Agronomy farm near Pullman, Washington, 2016 (left photo), and WSU Northwestern Research and Extension Center near Mount Vernon, Washington (right photo). Top photo: Rachel Wieme; bottom photo: Daniel Packer.

Expected Yield

According to current published research and experiential outcomes, a quinoa seed yield of 1,500 lb/acre would be a reasonable yield for Washington growers. The quinoa production in Colorado, southeastern Idaho, and California averaged yields of 1,500–1,800 lb/acre in 2018. Yields as high as 3,200 lb/acre have been reported, but there are also common observations of yields lower than 900 lb/acre or complete crop failures for U.S. trials (Weaver 2013; O'Connell 2015; Peterson and Murphy 2015; Buckland et al. 2018; Saint 2018; Wieme et al. 2020a). Reports of yields in Saskatchewan, Canada, for the years 2000–2005 ranged from 750 to 1,250 lb/acre (El Hafid et al. 2005), and in recent years yields over 2,000 lb/acre were reported. Published yields from other regions of the world demonstrate that with appropriate varietal development and selection paired with proper management techniques, quinoa has the potential to consistently yield between 1,800 to 2,700 lb/acre (Garcia et al. 2015; Peterson and Murphy 2015).

Table 1 shows some of the top performing varieties available in recent years for eastern and western Washington. In general, there have been wide ranges of yields in Washington climates, but as more selections are made towards developing adapted varieties, yields will improve and become more stable. Multiple experimental lines that were developed within the WSU variety trials reached yields over 3,500 lb/acre in 2018 under organic management and over 3,000 lb/acre under conventional management. There are not many published reports that directly compare yields of quinoa varieties under conventional and organic management in otherwise similar systems. The WSU variety trials are now testing genotypes under conventional and organic management each year; in 2018 average yields and protein contents were higher in the organic trials compared to the conventional trials.

Table 1. Experimental yields of available varieties from recent years for trials in eastern (near Pullman) Washington and western Washington (near Chimacum or Mount Vernon).

Variety	Eastern WA Yields (lb/acre)			Western WA Yields (lb/acre)		
	2014	2015	2016[a]	2014	2015	2018[b]
Titicaca	1,048	377	107	2,592	995	3,229
QQ74	353	149	71	2,069	566	3,385
Puno	455	118	0	1,730	584	3,158
Kaslaea	523	164	2	2,250	465	2,781
Redhead	107	4	0	1,316	134	2,743
NL-6	755	142	0	1,482	369	
Isluga	332	107	5	1,818	474	
CO 407 Dave	351	253	0	1,393	598	
Linares	317	98	5	1,776	251	
Black	91	91	8	1,730	491	
Blanca	146	24	10	1,647	501	
KU-2	433	138	32	1,863	445	
Cahuil	73	22	11	1,483	365	
Temuko	97	20	0	1,144	297	
Cherry Vanilla	124	11	13	1,451	35	

[a] Possible herbicide residue through part of the trial field and equipment issues at harvest contributed to low yields for this year. Variety trials were not performed in eastern WA after 2016.

[b] 2018 yield numbers are the average of the organic and conventional trial yields. Organic yields were higher than conventional yields and for all of the varieties listed here. More newly developed experimental lines were included in the variety trials starting in 2018, so fewer of the named available varieties were tested.

Agronomy

Seeding

Ideal planting time will depend on the location and the variety selected, but for most of the quinoa in Washington (average 120 days to maturity), early spring planting will be best. Quinoa can be direct seeded as soon as soil is dry enough to be prepared, with optimal germination occurring at soil temperatures ranging from 40°F to 60°F. Lower temperatures may slow emergence, but once emerged, quinoa seedlings are able to tolerate light frosts.

Quinoa is a small seed and does best when planted at shallow depths. Planting should be ¼ to ½ in. deep, or at the shallowest depth where the seed will receive moisture for germination.

Row spacing for quinoa can vary between 5 to 24 in., depending on the variety and system preference. Closer spacing is more suitable for varieties that do not branch. Wider spacing allows for inter-row weeding to be performed mechanically (Figure 5). Plant height for healthy quinoa will range from 3 to 6.5 feet, depending on the variety.

Figure 5. Top photo: Young quinoa (24 days after seeding) seeded with a Monosem precision planter. Bottom photo: rows of quinoa six weeks after seeding with ten-inch row spacing by the Monosem precision planter near Pullman, WA. Photos: Rachel Wieme.

Planting rates vary from 5 to 15 lb/acre, or 20 to 50 plants/ft^2. Smaller operations can seed heavier and thin the plant stand after emergence for ideal plant spacing. The growing environment should be considered when determining both inter- and intra-row spacing. More humid environments may benefit from wider spacing if disease and preharvest sprouting are concerns, as wider spacing allows better airflow and evaporation following rain events. The variety morphology should also be considered, as some branching varieties might dry better compared to unbranched varieties that have a more compact inflorescence.

Transplanting is another option for quinoa stand establishment. Transplanting has the potential to help combat weeds and provide faster maturation of the quinoa plants, which can be beneficial in some quinoa growing environments. A study performed in western Washington found that transplanted quinoa had higher survival compared to direct-seeded quinoa emergence and resulted in a higher average yield than direct seeding both years. The direct-seeded quinoa was planted at 9 lb/acre and had an emergence of 71–90%, depending on location and date; transplants were planted at 28 plants per linear yard. The transplanted quinoa also had shorter, more branched plants that reached seed fill and maturity faster compared to direct-seeded quinoa; in 2016 harvest occurred on average 23 days earlier for transplanted quinoa (46 days, 23 days, and 0 days difference for the early, middle, and later planting dates, respectively) (Ludvigson et al. 2019). It is important to note that in 2016 the direct-seeded quinoa was not thinned to match the wider spacing of the transplanted quinoa so there was also a difference in plant population, which can also contribute to differing time to maturity for quinoa.

Quinoa transplants are prepared by planting a few seeds in 3 to 10 cm^3 containers and thinning to one plant per container once seedlings are established. Transplants are started about a month prior to transference to the field, so that plants with three to five true leaves are established but have not yet become root-bound in their containers. This usually leads to seeding transplants in late March or early April and planting them in the field in late April or early May.

Irrigation

Irrigation may be an important tool for quinoa cultivation by ameliorating the effects of heat stress. Results from WSU trials showed that irrigation substantially increased yields under heat stressed growing conditions in eastern Washington (Walters et al. 2016; Hinojosa et al. 2019). Once again, quinoa's response to abiotic stresses, including high temperatures, varies widely depending on variety. Some cultivars of quinoa have actually shown increased growth with higher temperatures but suffered yield losses when high temperatures are combined with other stressors like low water availability (Bazile et al. 2016; Hinojosa et al. 2018; Präger et al. 2018). Studies have shown that quinoa does well under deficit irrigation in hot and dry environments (Geerts et al. 2008; Pulvento et al. 2012); irrigation might also increase the level of saponin (see "Harvest and Processing"

below) on quinoa seeds and help deter pests (Gómez-Caravaca et al. 2012; Pulvento et al. 2012; Oeller et al., forthcoming). Furthermore, development and cultivation of quinoa varieties in eastern Idaho under irrigation have been successful (Liang et al. 2016; O'Connell 2017a, 2017b).

After germination, the most critical period for water availability begins after the 12-leaf stage from flowering to grain fill. Full irrigation through all stages can encourage taller plants that are susceptible to lodging or delay plant senescence, which makes harvest difficult. Yields of 940 lb/acre have been achieved with as little as 7 inches of seasonal water input, though optimal irrigation rate usually ranges from 9 to 15 inches (Liang et al. 2016). Irrigation levels necessary for quinoa will depend heavily on natural rainfall and the soil type on your farm; WSU's Irrigation in the Pacific Northwest calculators (WSU Extension 2020) are available to help determine custom irrigation requirements depending on your operation and local conditions. Continued investigation into the role of heat stress, water availability, and the interaction of these factors in quinoa is warranted.

Fertilization

There is a notable lack of published research on fertilizer recommendations for quinoa cultivated in Washington State. Early trials in Colorado resulted in fertility recommendations for quinoa around 120 lb nitrogen (N) per acre (Johnson and Croissant 1985). However, the recommendation was increased to 150–180 lb N/acre after more field research. Recommendations for quinoa in Canada suggest fertilizing as one would for canola (Guenther 2014).

In some cases, high levels of nitrogen were found to have adverse effects, as they can lead to lodging and delayed maturity (Johnson 1990; Oelke et al. 1992). Experimenters at WSU observed inhibited germination of quinoa when fertilizer is applied at seeding, likely from the fertilizer strength and proximity "burning" the small seeds (Peterson and Murphy 2015).

More studies are available on quinoa fertilization from European trials, though there are still large differences in nitrogen response across varieties, locations, and years. In general, the studies have shown ideal fertilization levels of 90–135 lb N/acre (Peterson and Murphy 2015). Quinoa typically produced greater yields in response to increasing fertilization levels; however, it was sometimes only a marginal increase in yield, especially for the upper ranges of N recommendations (Jacobsen et al. 1994; Darwinkel and Stølen 1997). There is evidence that quinoa is a luxury consumer: increased N uptake may result in greater biomass production, but not necessarily translate to grain yield. Furthermore, quinoa N utilization efficiency (or the amount of grain produced per unit of plant N) either remained the same or decreased under increasing fertilization (Schulte auf'm Erley et al. 2005; Razzaghi et al. 2012).

Many of the WSU field experiments with quinoa—including the variety trials prior to 2018—were performed without fertilizer inputs (Figure 6). A rotational study in eastern Washington demonstrated that quinoa used less nitrogen than cereals like spring wheat and barley, and it helped recycle N though the crop residue for the following year (Wieme et al. 2020b). For the variety trials 2018 and 2019, fertilizer was added according to the management practices for each of the Mount Vernon-area farms where the trials were located. In 2018, this consisted of an application of 103 lb N/acre in a preplant application for the conventional trial, in addition to 30 lb/acre of phosphorus (P), 60 lb/acre of potassium, 20 lb/acre of sulfur, as well as the micronutrients boron, zinc, and manganese. The organic trials received about 70 lb N/acre through granular chicken manure. The WSU variety trial data from 2018 indicate approximately 35–75 lb N/acre are exported with the quinoa crop at harvest, given the range of protein contents (11.7–13.6%) and yields (1,730–3,625 lb/acre).

Figure 6. A healthy stand of organic (unfertilized) quinoa ('KU-2') near Pullman, Washington, in late July 2014. Photo: Rachel Wieme.

Although contradictory reports exist on the response of quinoa to phosphorus fertilization, in general added phosphorus may not increase yields unless it is concurrent with added nitrogen in nutrient-limited systems (Oelke et al. 1992; Aguilar and Jacobsen 2003). Darwinkel and Stølen (1997) reported requirements of 62 lb P_2O_5/acre for quinoa before seed filling; therefore, existing levels of phosphorus in many agricultural soils are likely sufficient. Interestingly, quinoa belongs to a family of plants that typically does not form symbiotic relationships with the helpful arbuscular mycorrhizal fungi (which are most known for helping plants gain greater access to phosphorus in exchange for carbon).

Pests

Insects

Plant Bugs: Various plant bugs (family Miridae) have been commonly reported on quinoa grown in California, Washington, Idaho, and Montana, including *Melanotrichus coagulatus* and *Atomoscelis modestus*. The most frequently reported pests of Washington quinoa by far are *Lygus* spp. (lygus bugs), including the Western tarnished plant bug (*Lygus hesperus*) and the pale legume bug (*Lygus elisus*).

Lygus bugs can cause damage to developing flowers and seed, or destroy terminal meristems, as they pierce plant tissues to eat the sap (Godfrey et al. 2015). Lygus bug adults are flat, oval, and small (approximately ⅛ by ¼ in.). They vary in color from pale green to yellowish brown. Markings are reddish brown or black with the most distinctive marking being the large, light-colored triangle in the center of the back (Figure 7). Young lygus bugs (nymphs) look similar to adults, but they are uniformly pale green with no wings. Lygus bugs feed on reproductive structures and can cause seed abortion and major yield loss (Jackson et al. 1995).

Adult lygus bugs are mobile and can fly from nearby crops, preferring crops such as alfalfa, beans, potatoes, oats, and tomatoes (Godfrey et al. 2015), and this movement can make control difficult. However, *Lygus* populations on quinoa in eastern Washington were highest during the three-week period following bloom and preceding seed set (Oeller et al., forthcoming), which could offer an effective window to spray if growers choose to use insecticides once tolerances are established for quinoa (see the "Insect-Pest Management" section on page 8). Natural predators of lygus bugs include parasitoid wasps, bigeyed bugs, damsel bugs, minute pirate bugs, and crab spiders. There is some evidence of lower Lygus abundance on irrigated quinoa plants (Oeller et al., forthcoming).

Figure 7. Lygus bugs on quinoa plants in mid to late June near Pullman, WA. Photos: Rachel Wieme.

Aphids: Aphids are small, sap-sucking insects that can cause plant damage directly from their feeding habits and can be vectors for disease. They can also cause damage through their sugary deposits on the plants ("honeydew"), which can lead to disfigurement, block light interception, and increase the incidence of fungal diseases. Aphids are found most commonly on the underside of leaves; the leaves may curl and distort, and eventually become necrotic (Figure 8). Multiple species of aphids have been reported on quinoa, including the cowpea aphid (*Aphis craccivora*), black bean aphid (*Aphis fabae*), the Chenopodium aphid (*Hayhurstia atriplicis*), the pea aphid (*Acyrthosiphon pisum*), potato aphids (*Macrosiphum euphorbiae* and *Hayhurstia atriplicis*), and the green peach aphid (*Myzus persicae*) (Kellogg and Murphy 2017; Liang et al. 2016). Keeping fields and field borders free of weeds can help prevent generalist aphids from spreading. High levels of nitrogen fertilizer can favor aphid reproduction. Transplants should also be checked and clean before planting (Kellogg and Murphy 2017). Natural predators of aphids include lady beetles, parasitoid wasps, green lacewing larvae, and syrphid fly larvae (Flint 2016).

Wireworms: Wireworms are the larvae of click beetles and feed on planted seeds and young seedlings. When wireworms feed on roots of young plants, it causes wilting, stunting, and eventually possible death of quinoa seedlings. The largest impact wireworms have on yield is the dramatic reduction in plant stand density. Recently tilled pasture, fallow, and sod can result in high wireworm populations; if any problems with wireworms have been observed, the seeding rate should be increased to prepare for some seedling death. Ensuring proper planting depth and moisture for seeds and seedlings may help, as delayed emergence and reduced vigor may leave quinoa seedlings vulnerable to wireworms for a longer period of time (Kellogg and Murphy 2017).

Stem- and Petiole-Boring Larvae: Considerable damage of quinoa has been observed from stem- or petiole-boring insects. Some of the species identified include *Cosmobaris americanus* (sugar beet petiole borer) and *Scrobipalpa atriplicella* (goosefoot groundling moth larvae).

The goosefoot groundling moth is an invasive insect originally from Europe but now found widely throughout North America; it is a small (½ to ⅔ in.) moth with a mottled, brown head and wings and a cream-colored underside. They are known to feed on related species and are commonly damaging quinoa crops in the Canadian prairies (Mori et al. 2017). The larvae bore into quinoa stems to feed on pith and vascular tissue; depending on the growth stage of the quinoa when this occurs, it can lead to stunting or even abortion of growth and 100% yield loss. "Pin holes" may be evident from the larvae entering or exiting the stalk. At later growth stages, stem boring causes the quinoa stalks to be more susceptible to lodging (Figure 9).

Figure 8. Aphid infestations on quinoa plants near Pullman, WA (top left photo, top right photo). Curled leaves are a sign of ongoing or past aphid infestations (bottom left photo). Photos: Rachel Wieme.

Figure 9. Unidentified stem boring larvae and damage to quinoa stalks. Observed 2017 near Pullman, WA. Photos: Daniel Packer.

Insect-Pest Management: Insect-pest management will be important for quinoa production to ameliorate the rates of direct damage from the aforementioned pests. Furthermore, indirect damage can be caused from insects when they act as vectors of various plant viruses, to which quinoa is notoriously susceptible. Until recently, no synthetic insecticides were registered for use in quinoa, so cultural and biological management options were the tools available for insect-pest management. Appropriate seeding dates and rates along with correct moisture and nutrient management practices help to produce vigorous plants that are less susceptible to insect damage. Crop rotation can help break pest life cycles, and increased habitat biodiversity (e.g., using mixed cropping) can help support natural insect predator populations (Figure 10).

In recent years, however, tolerances for quinoa were established for some chemicals, and a few have been registered in Washington State. They include: (1) chlorantraniliprole (Prevathon), a group 28 insecticide that targets insects of the order Lepidoptera (moths/caterpillars) and some Coleoptera (beetles), as well as (2) spinosad (Entrust), and (3) spinetoram (Radiant), which also target Lepidoptera larvae, various Diptera (flies), and thrips. There will be more research performed with these chemicals on quinoa for the region in upcoming years.

Figure 10. At least 15 lady beetles on a quinoa plant, along with multiple aphids and sign of aphid activity (notice the curled leaves near the base of the seed head and "honeydew" throughout the plant), and two lygus bugs. Late July 2016 near Pullman, WA. Photo: Rachel Wieme.

Weeds

Effective weed control is a significant challenge in Washington quinoa cultivation. Species of related *Chenopodium*, such as *C. berlandieri* and *C. album* (lambsquarters), are some of the most common weeds in Washington-grown quinoa, and it can be difficult to differentiate *Chenopodium* weeds from quinoa early in the season. Furthermore, quinoa tends to have a period of slow growth after germination, during which the weedy *Chenopodium* species and other weeds can surpass and overwhelm the crop, thus substantially decreasing yield. Until recently, there were no legally approved herbicides in the United States for use in quinoa. There are still none that can differentiate between quinoa and *Chenopodium* weeds, so even in conventional systems weed control is still a major barrier.

For smaller acreage, inter-row weeding with a cultivator is possible with wide row spacing. Dense planting into a clean seed bed may help combat weeds in areas where no in-season management is practical (Figure 11). Crop rotation can be helpful for weed management as well; for example, in a cropping systems study near Pullman, Washington, weed pressure in quinoa was lower following barley than it was following chickpea (Wieme et al. 2020a). Transplanting is another practice to help quinoa have an advantage over weeds, by allowing for faster maturation of the quinoa plant after being placed in a clean planting area.

Figure 11. A young stand of quinoa near Pullman, WA, planted with five-inch row spacing (2014). Photo: Rachel Wieme.

Disease

In high rainfall areas—like the western portions of Washington—downy mildew (*Peronospora variabilis* Gäum) is the most damaging disease for quinoa. The symptoms include irregularly shaped patches of pink and yellow discoloration on the leaves, and grey sporulation on both sides is visible. These leaves will become pale and eventually die and defoliate. Regions with humid conditions should take action to prevent downy mildew as much as possible, such as increasing space between plants (inter- and intra-row) or orienting the field to

increase wind flow through rows (Kellogg and Murphy 2017). Overhead irrigation should be avoided in quinoa.

Other fungal pathogens affecting quinoa include damping off (*Sclerotium rolfsii*), stalk rot (*Phoma exigua* var. *foveata*), leaf spot (*Ascochyta hyalospora*), and grey mold (*Botrytis cinerea*) (Oelke et al. 1992; Kellogg and Murphy 2017).

Harvest and Processing

Quinoa is ready to be harvested when the seeds reach the hard-dough stage, and when plants have senesced and most leaves have dropped. Mechanical harvest works best when the plants are completely dry, as this allows for easier separation of the seed from the panicle along with better mulching of the stalk biomass through the combine. If the plant is not completely dry, the stalks and excess biomass can clog combines or greatly reduce the efficiency of seed capture by the combine (Figure 12).

Figure 12. Top photo: a plot of spring barley ready to harvest while quinoa ('Cherry Vanilla') continues maturing in August near Pullman, WA. Bottom photo: quinoa nearing maturity at the end of August near Pullman, WA. Photos: Rachel Wieme.

If seeds have reached maturity but the plants have not completely dried down for combine harvest, quinoa plants can be swathed to allow the remaining vegetation to dry and then be threshed. Swathing and drying can be especially useful in climates when fall rains might coincide with harvest timing. Along with the risk of preharvest sprouting, quinoa is susceptible to lodging if there are prolonged rain events or wind, especially when the heads are filled with seed (Figure 13). As with any grain or seed crop, quinoa must be stored at an appropriately dry moisture content to maintain its quality and avoid damages such as spoilage and fungal infestations. Storage moisture content recommendations for quinoa have not been published, but the recommendations of 12–14% moisture content given for most grain and seed crops is likely appropriate for quinoa. Quinoa has the advantage that most of the equipment and protocols used to clean, dry, and store other grain and seed crops can be readily applied. Discussion of these methods are available from many University Extension Services, such as the Grain Drying and Storage website materials published by North Dakota State University (NDSU 2019).

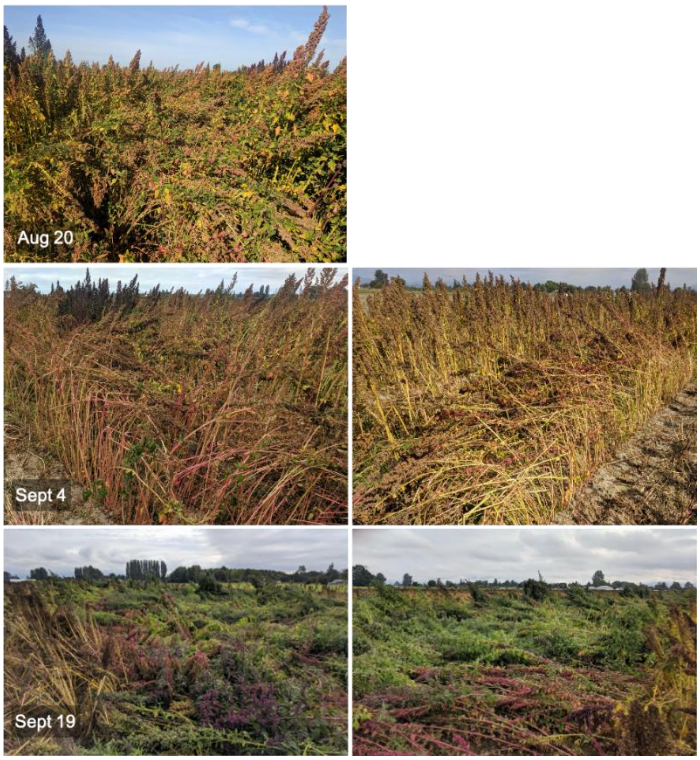

Figure 13. Extreme lodging in the 2019 variety trials (near Mount Vernon, WA) after multiple rain events throughout the season. Photos: Daniel Packer.

Before human consumption, quinoa must be processed to remove bitter saponins in the outer seed coat through abrasion or washing. Currently only two facilities for quinoa processing exist: one in Yuba City, California, run by Andean Naturals/Ardent Mills and the other in Idaho Falls, Idaho, operated by Clark Seeds/American Mills. Shipping quinoa to these facilities is an added expense for growers. For a grower in Washington State, shipping to either of these facilities represents a distance of 500 miles or greater. Additional labor and equipment are required if growers choose to remove saponins themselves.

Economics

The increase in demand for quinoa over the past decade has caused a sharp rise in its farmgate price, as production of quinoa struggled to keep up with that demand. Quinoa prices appear to have stabilized again near the pre-boom prices (prior to 2012). The high market price of quinoa was one motivation for some of the early experimenters and adopters of quinoa—especially smaller farms—but, on the other hand, the high prices and instability of quinoa supply did not allow for greater expansion and use of quinoa as an ingredient in value-added products. With more stable pricing and production, this may be a possibility for the future and strengthen or expand the current domestic quinoa market.

Quinoa seed prices have decreased as more varieties become available for production in the Pacific Northwest. Average seed prices are around $2.00/lb from some sources, though it still may be difficult to find large quantities of seeds for those seeking to expand their acreage in quinoa.

A cropping systems study near Pullman, Washington, growing quinoa in 2014–2016 found that the organic quinoa averaged sales of $157/acre and production costs of $104/acre, leaving $53/acre in returns over variable costs. When ownership costs were considered (on a typical share rental agreement that is dependent on the crop value), quinoa resulted in a loss of $31/acre (Wieme et al. 2020a). These analyses were done based on average equipment use and organic practices for a 1000-acre farm. The yields during this experiment were especially low, averaging 94 lb/acre. With improved varieties that stabilize the yield in this region, the returns would improve greatly. For example, using average prices from that period ($1.52/lb harvested quinoa and $4.66/lb quinoa seed planted at 5.5 lb/acre), a yield of only 164 lb/acre would be needed to break even over total costs for that organic production system. Alternatively, if the moderate yield goal of 900 lb/acre were achieved, quinoa prices could be as low as $0.69/lb and still break even over total costs.

Quinoa production and prices are not yet officially tracked in the United States, so published data on prices are not widely available. However, based on communication with businesses that are involved in the small pockets of western U.S. quinoa production, prices for 2019 were averaging about $0.85/lb for conventionally grown quinoa, and $0.97/lb for organic quinoa. Production is often contracted so seed prices are even more scarce, but there have been reports of seed costing around $2.00/lb from some regional providers of conventional quinoa seed. There are also some regional companies that sell multiple varieties of conventional and organic quinoa seeds suited to the region (see Kellogg and Murphy, 2017); however, at this point, they are still only selling smaller quantities. Washington State University research is working towards increasing access to regionally adapted varieties (Figure 14).

Figure 14. Harvested quinoa seeds from the Pacific Northwest. Far left, variety 'Red Head' seed sourced from Wild Garden Seeds in Oregon. Then left to right, varieties 'Red Head,' 'Puno,' and 'Titicaca' harvested from the WSU quinoa variety trials in western Washington. WSU seeds have been cleaned from chaff but have not been through full processing for saponin removal. Photo: Rachel Wieme.

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