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Effects of cultural practices at harvest on onion (*Allium cepa*) bulb quality and incidence of bacterial soft rot and fungal moulds after simulated shipping

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Abstract A field study was carried out to investigate the effects of cultural practices at and after harvest on onion (*Allium cepa*) bulb quality and incidence of storage rots and fungal moulds after both ambient and refrigerated simulated shipping. Onion plants were lifted at one of two stages of maturity, cured under three moisture conditions, and topped at two different times. Refrigerated simulated shipping reduced the incidence of rots, even in bulbs cured under dry or ambient moisture conditions, from 2.6% to 0.9%. Refrigeration also reduced the severity of surface moulds; the percentage of bulbs with commercially undesirable levels being reduced from 54% to 21%. Refrigeration also resulted in outturn of a larger proportion of bulbs with green-yellow skins. The combination of topping before field curing and wet conditions during field curing increased the incidence of rots in bulbs after simulated shipping in ambient and refrigerated conditions. Dry field curing conditions increased the incidence of skin splitting in bulbs lifted at 90% top-down, but not in those lifted at 25% top-down, where average incidence of splitting was less than 1%. Lifting at 25% top-down resulted in a greater proportion of bulbs with two or more intact outer skins, and reduced the incidence of skin splitting. Modification of husbandry practices, monitoring of the weather during harvest, and refrigerated shipping are recommended as measures to reduce the incidence of bacterial soft rot and improve the quality of onion bulbs in storage and transit.

Keywords onion; *Allium cepa*; soft rot; curing; harvest; agronomic methods; bulb quality; storage

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INTRODUCTION

Fresh onions (*Allium cepa* L.) are New Zealand's highest valued export vegetable, with earnings of over NZ$100 million for the year ending 30 June 2002 (Statistics NZ). The United Kingdom and Europe are the biggest markets for New Zealand onions, taking over 75% of total onion exports (Statistics NZ). The production of high quality onion bulbs that are able to withstand long transportation distances to export markets is fundamental to the New Zealand onion export industry (Wright & Grant 1997). Onions from New Zealand are transported by ships either loose in containers, in large wooden bins, or in netting bags or large netting bulk bags (Wood 2001). The cargo is shipped at ambient temperatures and humidities in conventional holds, in standard containers with the door off, in modified fan-ventilated containers, and in temperature-controlled containers (Wood 2001).

The New Zealand onion industry is based upon selections and hybrids from the traditional intermediate day-length cultivar 'Pukekohe Longkeeper' (PLK), a globe-shaped, brown-skinned, and pungent onion that can be stored for up to 9 months. In recent years, the range of onion types exported from New Zealand has increased to include red varieties, sweet onions, and Japanese hybrids (SoFresh). Desirable quality characteristics of harvested onions include bulbs that are free of diseases and that have clean, unblemished skins that do not split or are loose, and have a colour appropriate to the cultivar (Tucker & Drew 1982). Research carried out in New Zealand and internationally has demonstrated that the methods by which onions are harvested and cured, and the prevailing weather conditions during harvest, can have important effects both on onion quality characteristics and storage life (Currah & Proctor 1990; Wright & Grant 1997).

The commercial value of onions is largely determined by their appearance. The most desirable colour for PLK bulbs is a deep golden-brown, and although skin colour does not affect storage performance, onions with blemished or pale, greenish skins are considered inferior (Wright et al. 2001). Temperature conditions after harvest can influence the colour of the outer skins of onion bulbs (Bleasdale & Thompson 1966). Loss of outer skins of harvested onions not only detracts from their appearance but also accelerates desiccation of bulb tissues, reducing storage life and lowering commercial value (Tucker & Drew 1982; Wright et al. 2001). Skin stains and blemishes, mainly caused by fungi that develop on the surfaces of bulbs when they are exposed to wet conditions during field curing and storage, also reduce the visual appeal of the onion bulbs without affecting their storage life (Rickard & Wickens 1977; Tucker & Drew 1982). Other fungi, including *Aspergillus niger* (black mould), *Penicillium* spp. (blue mould), and *Botrytis allii* (neck rot), can infect fleshy bulb scales when onions are stored in warm conditions where relative humidity is high, causing decay of onions (Schwartz & Mohan 1995). These fungi produce copious quantities of fungal spores on and under the papery scales of bulbs, which significantly downgrade the quality of the shipment (Currah & Proctor 1990). Refrigerated storage slows the development of these diseases, although fungal growth is resumed on return to higher temperatures (Schwartz & Mohan 1995).

Soft rot, caused by several species of bacteria, is a major post-harvest disease of onions grown in New Zealand (Wright & Hale 1992; Wright et al. 1993a, 2001). Soft-rotting bacteria exist as saprophytes in plant debris in the soil, and invade onion bulbs through wounds, senescent or dead leaves, or improperly dried necks (Wright et al. 2001). The early stages of soft rot are not noticeable at grading and, as a consequence, export of infected onions can occur (Wright et al. 1993b). Infected onions will rot in transit if storage and shipping conditions favour soft-rot development (Snowdon 1991; Schwartz & Mohan 1995).

In New Zealand, the traditional method of harvesting onions is to lift the bulbs when 60–80% of the tops have fallen over followed by a field curing period of up to several weeks, the time depending on factors such as rainfall, and maturity at harvest, then removal of foliage (topping) and storage (Wright et al. 2001). To meet consumer demand and obtain premium prices many New Zealand growers have started to use non-traditional harvest practices to produce onions of higher quality (Wright & Grant 1997; Wright et al. 2001). Perhaps as a result of this, the incidence and severity of bulb rots, and bulbs with poor skin quality (split skins, staining, and fungal moulds) on arrival at export destinations has also markedly increased in recent years (Wright & Grant 1997; Wright et al. 2001).

This paper describes the effects of physiological maturity of onion plants at lifting (percentage top-down) and method of curing on skin colour, skin splitting and retention, the incidence of moulds (black, blue, and grey), and the incidence of bacterial rots for onion bulbs grown in the Pukekohe district of New Zealand.

MATERIALS AND METHODS

A trial was carried out at the Crop & Food Research Centre at Pukekohe, on a Patumahoe mottled clay loam. Seeds of the onion cultivar PLK (‘May and Ryan Regular’ strain) were direct-seeded on 18 July 2002 using a Stanhay precision seed planter in four beds (each of five rows). Each bed was 60 m long and 1.5 m wide. Plant density 1 month after seedling emergence was 55–65 plants/m of bed. Base fertiliser, weeds, pests, and diseases were managed using local commercial practice. Nitrogen (N) was applied at 120 kg N/ha (as urea) in two equal applications at early crop emergence and 8 weeks later. To create soft, succulent foliage favourable for bacterial soft-rot infection, onions were given further applications of 60 kg N/ha on 9 December and 30 December, and were irrigated on 30 December and 2 January.

There were 24 treatments in the trial, which was of a complete factorial design with four factors. Of the three field factors, two, lifting and topping times, each at two levels, affected the method of harvesting whereas the third field factor reflected three levels of moisture during field curing. The fourth factor, shipping conditions, had two levels. Each of the 12 combinations of the field factors had four plots, 5 m long × 1.5 m wide, which were randomised within four blocks.

Onion bulbs were lifted at two stages of maturity. Half the onions were lifted on 27 January 2003 when

25% of the plants had collapsed foliage (top-down). The other half were lifted on 10 February 2003 when they had 90% top-down.

Hand shears were used to remove the foliage to 2–3 cm above each bulb, either immediately after lifting or after a field curing period of 4 days. Field curing was carried out at three locations, each under different moisture regimes. In the "wet" conditions during field curing treatment, plants were placed back on the soil where they had grown and were watered by overhead irrigation for 30 min each morning and late afternoon. In the "ambient" conditions during field curing treatment, the onions were moved 10 m so that they were out of range of irrigation water. No rainfall occurred during the ambient curing period. To simulate field curing under dry conditions, in the "dry" treatment, onions were moved to a fully vented greenhouse to prevent moisture affecting them.

After the lifting, curing, and topping treatments, two random samples of 50 bulbs (for disease and bulb quality assessments) of 60–90 mm diameter from each plot were placed in nylon string bags and moved to forced-air dryers to complete the curing process. Unheated outside air was forced through the onions at a rate of 14 m^3/min by a blower fan for 7 days. Onions were held in a ventilated shed at ambient temperature (range 12–22°C) and humidity (range 70–85% RH) until all lifting, curing, and topping treatments and forced air curing had been completed.

Onions were then subjected to a storage treatment, lasting 31 days, simulating shipping to Europe in either ambient or refrigerated conditions. The two bags of onions from each plot were randomly assigned to the two shipping treatments. In the treatment simulating ambient shipping, temperatures started at 20°C, steadily increased to 30°C after 20 days, and then declined to 23°C during the next 10 days. Relative humidity was 80–95% for the first 23 days and 55–65% during the next 8 days. In the refrigerated shipping treatment, the temperature was kept at 7°C and the relative humidity c. 85% for the whole period.

After simulated shipping, each bulb was visually assessed for skin colour, number of skins, presence of splits in skins (exposing fleshy bulb scales), surface mould, and soft rot.

The primary skin colour of each bulb was scored using the following 1–5 scale: 1 = green-yellow, 2 = straw yellow, 3 = golden-brown, 4 = brown, 5 = dark brown. Surface moulds were assessed using a 1–5 scale, where 1 = 0% of the bulb covered with mould, 2 = 1–10% mould-covered, 3 = 11–25% mould-covered, 4 = 26–50% mould-covered, 5 = >50% mould-covered. All bulbs from each treatment sample were cut in half and the number of intact outer dry skins of each bulb was counted and the bulbs examined for soft rot. Rot was classified into two categories: either "major" rots, where rot extended more than halfway down one or more fleshy bulb scales, or "minor" rots, where rot extended less than halfway down one or more fleshy bulb scales.

The fundamental experimental unit was a bag of 50 onions. The experiment was thus a split-plot design with the three field treatment factors constituting the whole-plot factors and the shipping treatment being the subplot factor. Data were in the form of percentages. Before analysis the data were transformed to the arc-sine (or angular) scale to stabilise variance.

RESULTS

Major rots

The effect of simulated shipping conditions had the biggest effect on major rots (rot extending more than halfway down one or more bulb scales), with these conditions explaining 66.1% of the total variation between treatments. The incidence of major rots was much lower (mean 0.04%) in the bulbs from the refrigerated simulated shipping treatment than with the ambient simulated shipping bulbs (mean 4.7%) ($P < 0.001$) (Table 1).

The effect of moisture during field curing, and its differential effect during simulated shipping ($P < 0.001$), explained a further 19.3% and 6.4% of variation between treatments respectively. In refrigerated bulbs there were no statistically significant differences ($P > 0.05$) in the incidence of major rots for all three conditions of moisture during field curing, with levels of soft rot all between 0% and 0.3% (Table 1). However, in bulbs from the ambient simulated shipping treatment, those that were subjected to additional water during field curing had a greater incidence of major rots (mean 11%) than those subjected to ambient (2%) or dry (3%) field curing conditions ($P < 0.05$).

The effects of topping, and its differential effect in simulated shipping, explained 3.2% and 2.4% of variation between treatments respectively (both $P < 0.001$). Onions topped before field curing had a higher incidence of major rots (6.6%) than onions topped after field curing (3.2%) for ambient ($P < 0.05$), but not refrigerated, simulated shipping conditions (Table 2). There was no statistically significant interaction between time of topping and moisture during field curing with regard to the combined effect of these factors on the incidence of major rots in bulbs after simulated shipping. The combination of topping before field curing, wet conditions during field curing, and ambient simulated shipping led to 15% of the bulbs with major rots.

The time of onion lifting and its differential effect on or interaction with time of topping and moisture conditions during field curing did not affect the incidence of major rots ($P > 0.05$).

Minor rots

For minor rots, simulated shipping conditions was the most important factor, explaining 69.0% of variation between treatments. The incidence of minor rots was greater in bulbs in the refrigerated simulated shipping treatment (mean 1.5%) than in bulbs in ambient conditions (0%) ($P < 0.05$) (Table 3). Moisture during field curing was the next most important factor, explaining 11.6% of the variation between treatments. Onions subjected to wet field curing conditions had the highest incidence of minor rots in refrigerated simulated shipping bulbs (mean 3.7%). Dry and ambient conditions during field curing resulted in 0.5% and 1.2% minor rots respectively from the refrigerated simulated shipping treatment. Time of onion lifting and time of topping did not affect the incidence of minor bulb rots ($P >$ 0.05).

Skin colour

Simulated shipping conditions had the greatest effect on bulb skin colour, with this factor explaining 98.9% of the total variation between treatments. For refrigerated onions, 45.1% had skin colour scores of 1 (commercially undesirable green-yellow colour) compared with 6.6% of ambient treated onions ($P <$

Table 1 Differential effect of moisture during field curing on incidence of "major" rots of 'Pukekohe Longkeeper'onion (*Allium cepa*) bulbs during simulated shipping under ambient or refrigerated conditions. Percentage bulbs with major rots back transformed from fitted means on arc-sine scale. LSDs refer to means of arc-sine transformed data (in parenthesis). $LSD_{0.05}$ (d.f. = 71) = 1.3, 1.5, 2.2 for shipping, moisture and shipping × moisture means respectively.

	Moisture during field curing			
Shipping conditions	Dry	Ambient	Wet	Mean
Ambient	2.7	2.4	11.0	4.7
	(9.4)	(8.9)	(19.4)	(12.6)
Refrigerated	0.0	0.0	0.3	0.04
	(0.0)	(0.5)	(3.0)	(1.2)
Mean	0.7	0.7	3.8	
	(4.7)	(4.7)	(11.2)	

Table 2 Differential effect of time of topping on incidence of "major" rots of 'Pukekohe Longkeeper'onion (*Allium cepa*) bulbs during simulated shipping. Percentage bulbs with major rots back transformed from fitted means on arc-sine scale. LSDs refer to means of arc-sine transformed data (in parentheses). $LSD_{0.05}$ (d.f. = 71) = 1.3, 1.3, 1.8 for shipping, topping and shipping × topping means respectively.

	Time of topping (relative to field curing)		
Shipping conditions	Before	After	Mean
Ambient	6.6	3.2	4.7
	(14.9)	(10.3)	(12.6)
Refrigerated	0.1	0.0	0.04
	(1.3)	(1.0)	(1.2)
Mean	2.0	1.0	
	(8.1)	(5.6)	

0.001). The predominant bulb skin colour in refrigerated onions was green-yellow (score 1), and the percentage of bulbs in each successive skin colour category decreased (Fig. 1). With ambient simulated shipping treatment, the predominant bulb skin colour was golden-brown (score 3). The time of lifting, method of topping, and moisture conditions during field curing did not affect bulb skin colour ($P > 0.05$).

Surface moulds

Simulated shipping conditions had the greatest effect on the severity of skin surface moulds, with this factor explaining 91.0% of the total variation between treatments. A greater proportion of bulbs had severe surface moulds (mould scores of 4 and 5) following ambient simulated shipping conditions (54%) compared with those in refrigerated conditions (21%) ($P = 0.001$). The predominant mould score in refrigerated bulbs was 2 (1–10% of surface of bulb covered with mould), and the percentage of bulbs in each successive mould category decreased (Fig. 2). With ambient simulated shipping, the percentage of bulbs with mould scores of 2, 3, 4, and 5 ranged from 20% to 29%. Time of lifting, time of topping, and moisture conditions during field curing did not affect the severity of surface moulds ($P > 0.05$).

Number of skins

The major influences on the variation in the number of intact skins were time of lifting (explaining 78.7% of variation between treatments), and time of topping (10.1%). Onions lifted at 25% top-down had fewer (2.5%) onions with 0–1 skins than onions lifted at 90% top-down (6.8%) ($P < 0.001$). Onions topped before field curing had a lower incidence of bulbs with 0–1 skins (3.6%) than onions topped after field curing (5.2%) ($P < 0.05$). Moisture during field curing and shipping conditions did not affect retention of outer bulb skins ($P > 0.05$).

Split skins

The major influences on the variation in the incidence of split skins were time of lifting (explaining 78.8% of variation between treatments), and moisture conditions during field curing (17.5%). Onions lifted at 25% top-down had fewer bulbs with split skins (0.8%) than onions lifted at 90% top-down (6.2%) ($P < 0.001$). Onions field cured under dry conditions had a higher incidence of skin splits (4.7%) than onions cured under ambient (2.8%) or wet (1.6%) conditions ($P < 0.05$). Bulbs given ambient simulated shipping conditions had more spilt skins (3.3%) than refrigerated bulbs (2.5%) ($P < 0.05$). Time of topping did not affect the incidence of skin splitting ($P > 0.05$).

DISCUSSION

This study has clearly demonstrated that harvest operations and prevailing moisture conditions during field curing are important factors affecting onion soft rot in store. The results of the experiment confirm the findings of Wright et al. (1993b) that cutting of onion tops at harvest facilitates infection by soft-rotting bacteria, and that warm, wet conditions during field curing can increase the incidence of post-harvest rots. Onion crops should not be lifted too early (before 50% top-down) because the foliage will take longer to dry during field curing, especially

Table 3 Differential effect of moisture during field curing on the incidence of "minor" rots of 'Pukekohe Longkeeper' onion (*Allium cepa*) during simulated shipping. Percentage bulbs with minor rots back transformed from fitted means on arc-sine scale. LSDs refer to means of arc-sine transformed data (in parentheses). $LSD_{0.05}$ (d.f. = 71) = 1.0, 1.3, 1.8 for shipping, moisture and shipping × moisture means respectively.

	Moisture during field curing			
Shipping conditions	Dry	Ambient	Wet	Mean
Ambient	0	0	0	0
	(0)	(0)	(0)	(0)
Refrigerated	0.5	1.2	3.7	1.5
	(4.1)	(6.3)	(11.1)	(7.2)
Mean	0.1	0.3	0.9	
	(2.0)	(3.2)	(5.6)	

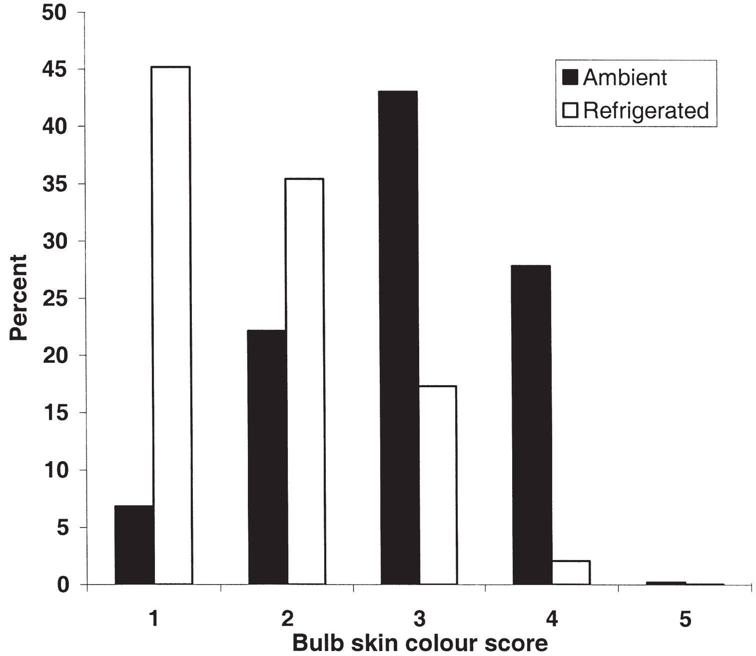

Fig. 1 Distribution of skin colour grades of onion (*Allium cepa*) 'Pukekohe Longkeeper' bulbs after ambient and refrigerated shipping. 1, green-yellow; 2, straw yellow; 3, golden-brown; 4, brown; 5, dark brown.

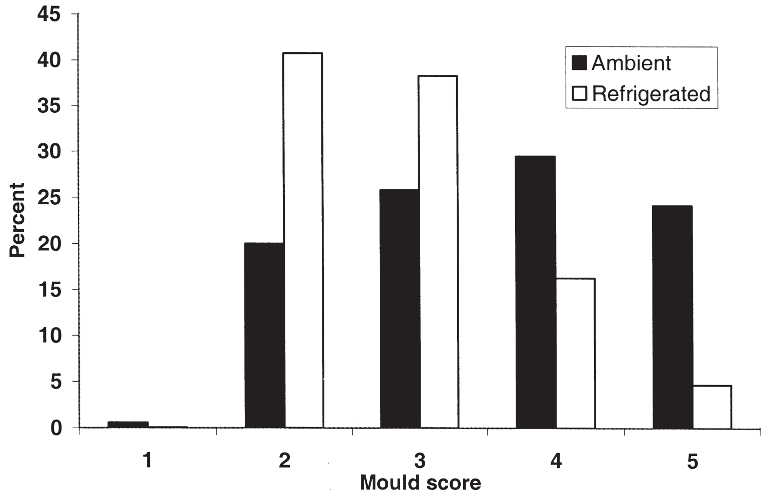

Fig. 2 Distribution of mould scores of onion (*Allium cepa*) 'Pukekohe Longkeeper' bulbs after ambient and refrigerated simulated shipping. 1, 0% of the bulb covered with mould; 2, 1–10% mould-covered; 3, 11–25% mould-covered; 4, 26–50% mould-covered; 5, >50% mould-covered.

if wet weather persists during this time, resulting in a higher incidence of wounding during topping (Wright et al. 1993b). During field curing, onions should be exposed to warm, dry air in the field to dry the tops and "seal" the bulb necks, preventing infection via wounding at topping. Onions should not be lifted if wet weather is forecast. However, it should be noted that the study was carried out during just one growing season, and the additional nitrogen fertiliser to help soft rot infection is not normal commercial practice.

The time of lifting, the level of moisture during field curing, and simulated shipping conditions all affected the incidence of skin splitting. Time of harvest affected skin retention of bulbs, with later-harvested bulbs having fewer intact outer skins than those harvested earlier. It is preferable to lift onion bulbs before all the tops have fallen to encourage drying off without excessive skin loss. Onion yields can increase by as much as 30–40% between the time when foliage begins to collapse until it has fully senesced, but as lifting is delayed the incidence of skin loss and cracking increases (Brewster 1990).

The effect of temperature during curing and storage on the development of onion skin colour has been well documented, and was confirmed by the present study. Bulbs subjected to temperatures higher than 27°C develop darker skins than those at cooler temperatures (Bleasdale & Thompson 1966). At higher temperatures the concentration of natural pigments in the outer skins of bulbs is enhanced, resulting in darker bulbs (Sanguansri & Sutherland 1991). Although skin colour does not affect storage performance, the intensification of skin colour of PLK to a dark gold or brown is regarded as a desirable characteristic (Wright & Grant 1997). Bulbs that were stored at cool temperatures after harvest "darkened up" when they were returned to warmer temperatures.

The present study demonstrated that the temperature to which onions are subjected after harvest (during shipping/storage) was a very important factor affecting bulb soft rot. At cooler temperatures (7°C) soft rot developed slowly in infected bulbs. However, it can be expected that when infected bulbs that have been stored at low temperatures are returned to warmer ambient temperatures, rotting will continue to develop more rapidly—minor rot in a bulb will become a major rot. The higher cost of refrigerated shipping relative to ambient shipping may deter exporters. Furthermore, refrigeration may be unnecessary for onions harvested under optimal conditions. Nevertheless, bulbs that are likely to have post-harvest soft rot problems are shipped at low temperatures. Such onions include those that have been field cured in wet conditions—especially if they were topped "green" or are a soft rot susceptible cultivar (e.g., a mild/sweet red type).

Fungal moulds on the surfaces of bulbs in storage require both moisture and warm temperatures to develop rapidly. Bulbs should be dried promptly after harvest and stored in conditions where relative humidity is 60–80%. Good ventilation is important to prevent condensation of moisture on the surfaces of bulbs. Temperatures below 15°C will reduce the growth of black mould (Schwartz & Mohan 1995), and below 6°C will reduce the growth of blue mould (Maude 1983).

The level of humidity during storage is a major factor affecting several bulb quality characteristics including rots, surface moulds, and skin retention. Onions differ from most other horticultural produce in requiring a relative humidity of only 70–75% (Snowdon 1990). Respiring onions give off water vapour, and the relative humidity within a mass of bulbs is commonly over 90% (Snowdon 1990). Because the available air at sea is usually moisture-laden, it can be more difficult than on land to achieve and maintain a low enough relative humidity, regardless of method and temperature of shipping of onions (Snowdon 1990). Onions should be stored only after they have been properly dried, and in cool temperatures (<20°C) and relative humidity c. 70–75% with good ventilation to prevent condensation forming on bulbs.

New Zealand is a long way from its major onion markets. Production of a quality product that arrives at export destinations in excellent condition requires an integrated approach involving the use of suitable cultivars, appropriate production practices, optimal curing and post-harvest procedures, careful monitoring of the weather during harvest, and good shipping conditions.

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