STORAGE CONSTRUCTION FOR EFFECTIVE ULTRA LOW OXYGEN STORAGE IN AUSTRALIA

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The use of very low levels of O_2 in CA storage has appreciably reduced storage scald, breakdown, core browning and the rate of flesh softening on "Australian" apple cultivars when stored. In the case of pears, safe storage life has been extended and susceptibility to scald reduced. Where long term storage is intended, then hyper low O_2 (HLO) atmospheres (0.5% CO_2 + 0.7 to 1.0% O_2) are recommended for Granny Smith and Jonathan apples and for Packham and Bartlett pears. Ultra low O_2 (ULO) atmospheres (1.0% CO_2 + 1.4 - 1.6% O_2) are more suitable for Red Delicious, Golden Delicious and most other apple varieties grown in Australia. Initial O_2 stress (IOS) treatments (CO_2 < 1.0% + 0 - 0.4% O_2) which preceeded HLO and ULO storage reduce superficial scald and allows an appreciable reduction in the concentration of DPA used in postharvest drenching. Ideally, HLO and ULO storage should be operative within 7 - 10 days of harvesting. This is referred to as rapid CA (RCA).

The Storage Structure

The problem of air leakage into CA stores delayed the practical application of HLO and ULO storage by 5-6 years. With the introduction of metal clad polystryene panels, cheap free standing structures were built. These provided an effective thermal barrier, but were not always gas tight. Stores were often gas tight in the first year of operation but then became unreliable due to leakage at wall to floor or wall to ceiling junctions.

Sprayed-on polyurethane foam construction now provides us with a most effective method of gas proofing existing or new CA rooms. It also provides a continuous layer of efficient insulation and contributes to the structural strength of the cool room. Older polystryene panelled rooms are often gas proofed by spraying the interior with one inch of polyurethane. This method, however, does not overcome leakage which originates where wall panels are poorly sealed to the concrete base.

The plastic jacket room provides ideal CA conditions at low cost inside a conventional room. This system is able to breathe with atmospheric pressure change and air leakage is reduced to some extent. Condensation is a problem if the storage temperature of the produce is above $0^{o}C$.

The ideal design giving reliable and durable service for storage in subnormal O_2 is shown in Figure 1. This structure is expensive and incorporates features such as gable roofing, a breather bag and an outer weather wall. These features are omitted to reduce cost where stores are designed for short term CA or for air storage of pome and other fruits.

The Beginning of CA Storage in Australia

Following manufacture of the first catalytic generators and activated carbon scrubbers in Australia in 1968 the advantage of true CA storage where O_2 was maintained at less than 4% was demonstrated. However, the need for RCA to maximise the benefit of CA was soon recognised. This effect is illustrated in Figure 2 where softening on two apple cultivars stored in air or by RCA to ULO storage conditions is compared. Of 12 pome fruit cultivars assessed for loss of firmness during 0^oC storage in ULO or in air, Jonathan benefitted most and Granny Smith least from ULO treatments (Fig 2) and the benefit of ULO was more evident in the former than the latter 160 days of storage. Cultivars responding similarly to Jonathan are Mutsu, Delicious, Golden Delicious and Packham and Bartlett pears. Lady Williams, Democrate and Crofton apples tend to react similarly to Granny Smith.

Carbon Dioxide in CA Storage

Early work established safe levels for CO_2 where O_2 was maintained near 4%. The maintenance of CO_2 at levels higher than the O_2 levels reduced softening but increased flesh and core disorders. Maintaining CO_2 at levels below the O_2 concentration is difficult during initial generation as the production rate of CO_2 from generators used in recycling systems (CAPCO catalytic reactors) often exceeds the rate of CO_2 removed by activated carbon scrubbers. This can delay RCA, and the use of IOS treatments, and some operators prefer bulk N_2 flushing to obtain ULO storage. Lime placed in the CA chamber is an effective means of taking off respiratory CO_2 and is used at 5-6 kg/bin (400 kg) of fruit.

Where ULO is not possible because of ineffective gas sealing of storage structures it is beneficial to have higher levels of CO_2 in the storage atmosphere. Where stores fail a gas tightness test it is recommended that CO_2 and O_2 be equal if CO_2 sensitive strains (Jonathan, Granny Smith, Mutsu) are stored, and that CO_2 exceed the O_2 concentration if CO_2 tolerant strains (Packham pear, Golden Delicious, Red Delicious) are stored.

Benefits of Subnormal Oxygen Level

Storage scald (scald) appears on most Australian grown apple cultivars and on Packham pears which are stored for more than 6 months. Granny Smith is the cultivar most prone to scald and is used in storage trials investigating control measures. Scald is not reduced by conventional CA (storage in 3 to 3.5% CO_2 + 3 to 3.5% O_2) compared to air storage, but is reduced by ULO storage and further still by HLO storage. The effectiveness of HLO storage was matched by ULO storage which was preceeded by IOS for 10 to 15 days, but these treatments never completely controlled scald. However, while DPA at 3000 ppm is required to control scald on fruit grown in areas of highest susceptibility (hot plains country as compared to elevated areas or coastal locations) scald on similar fruit was controlled with 300 ppm DPA where storage was in ULO (Figure 3). Ultra low oxygen storage may only delay the onset of scald as storage for 8 and 9 months plus 14 days marketing required 100 ppm and 300 ppm DPA respectively to hold scald at less than 5% which is demanded by retailers.

Commercial CA operators using ULO are reluctant to reduce DPA rates since reversion to conventional CA, as a result of inadequate gastightness, would result in severe loss from scalding. However, since ULO storage only reduces core browning during long term storage if DPA has been applied at less than 1000 ppm (Figure 3) the application of 3000 ppm DPA as an insurance against failure is not a wise option.

Ethylene Accumulation in Static CA

Results of an ethylene monitoring programme conducted during the first 40 days of storage revealed higher levels in stores using open flame generators than recycling catalytic generators. Ethylene continued to increase in effectively sealed stores which were ideal for ULO storage and reached levels of 250 to 1200 ppm. While the presence of ethylene during conventional CA storage accelerated softening on Granny Smith, Delicious and Jonathans this effect was of greater consequence on Jonathans which often pressure test below 8-9 lbs resulting in adverse market reaction. In a trial situation in which ethylene was maintained at high (400-600 ppm) and low (3.0 - 6.0 ppm) levels softening was increased by high ethylene levels in conventional CA and this effect was evident after 20 weeks of storage + simulated marketing (10 days at 22^{o}C) or after 40 weeks of storage and prior to marketing (Fig.4). However, loss of firmness on Jonathans was not influenced by the presence of ethylene during ULO (Fig 4).

High ethylene during CA storage also induced flesh and core disorders of Jonathans, Granny Smith and Red Delicious. Response to high ethylene in storage depended on the CA treatment and maturity of the fruit. Core browning in Granny Smith was increased by high ethylene in conventional CA and ULO storage, but not in HLO storage (Figure 5). Where Jonathans of optimum maturity for long term CA were stored, the presence of high ethylene increased breakdown and brown heart in conventional CA but not in ULO. More mature Jonathans, however, were susceptible to these flesh disorders in conventional ULO and HLO storage where ethylene was high. Jonathan breakdown on fruit of optimum storage maturity was below 5% after 40 weeks of storage in ULO but exceeded 25% after 40 weeks in conventional CA (Figure 6), and combined wastage from breakdown and brown heart remained below 10% after 40 weeks in ULO. With the storage of overmature Jonathans, brown heart was reduced substantially by ULO and was further reduced by HLO (Figure 7) but total loss from brown heart and breakdown exceeded 10% after 40 weeks in HLO storage. The reduction of flesh disorders due to storage in ULO and HLO rather than conventional CA is minimal during early storage but substantial with long term storage (Figure 8). While IOS prior to ULO storage reduced breakdown after 20 and 40 weeks of storage, lowest wastage after the maximum storage period was achieved by HLO storage (Fig. 8).

COMMERCIAL APPLICATION

Packing house operators who have successfully used ULO first spent considerable time and money to obtain a gastight structure. Controlled air venting then maintained desirable O_2 levels and lime within the store removed respiratory CO_2. Maximum deviation above and below nominated CO_2 and O_2 levels did not exceed 0.3% during the initial 180 days of storage. Effective use of RCA to obtain IOS conditions reverting to ULO or HLO storage has been more difficult with catalytic generation than with bulk nitrogen flushing.

Although disorders are reduced in commercial ULO storage it is difficult to obtain a price premium. One large operator obtained reactions from his regular wholesale outlets. These are shown in Table 1. Another operator stated that it was a choice between return sales or having no return sales once disorders show up in conventionally CA stored lines if fruit from ULO is available. A large pear cannery was able to dispense with the high cost midnight shift because HLO storage allowed a 5 week extension in processing operations for Bartlett pears.

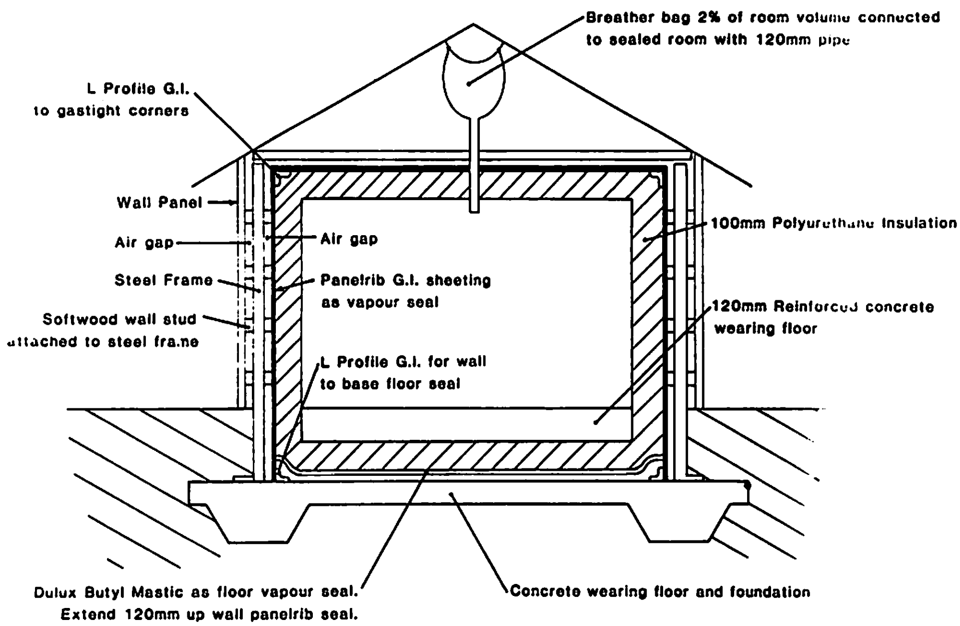

Fig 1 Design features of gastight stores currently built for ultra low oxygen storage in Australia

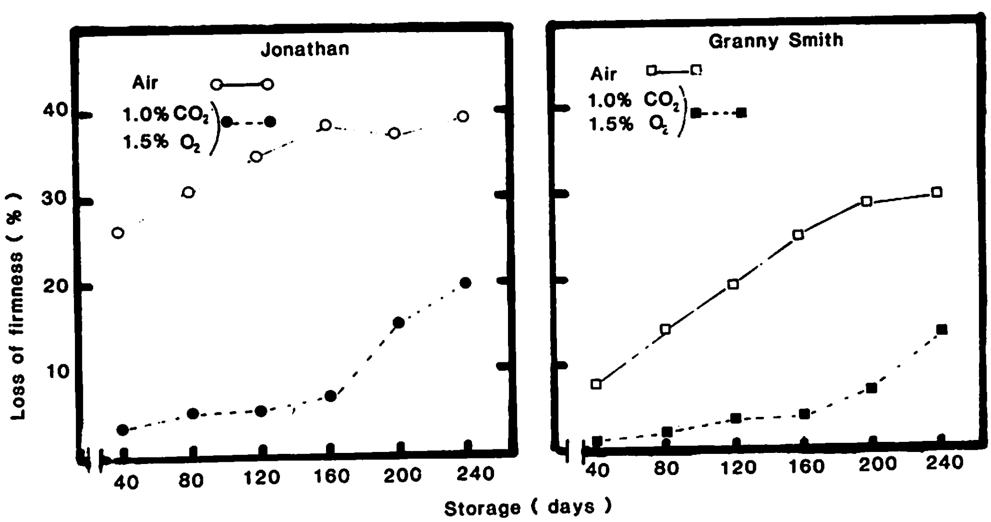

Fig 2 The effect of storage treatment and duration of storage on loss of apple fruit firmness since harvest

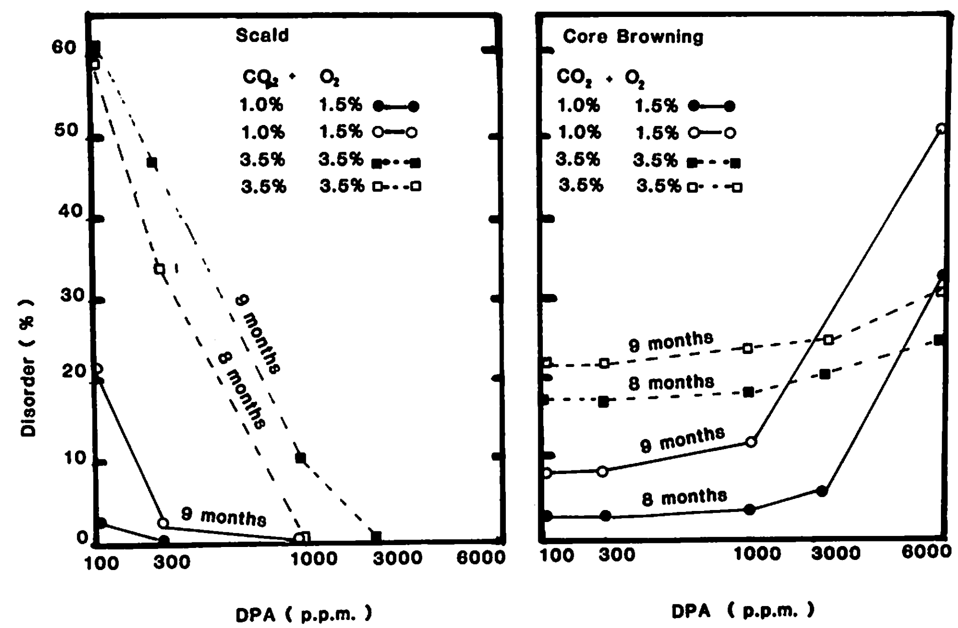

Fig 3 The effect of storage method on DPA requirement for scald control on Granny Smith and the adverse response to excessive DPA followed by ultra low oxygen storage on core browning (Initial O_2 stress (less than 0.4% for 12 days preceeded CA storage).

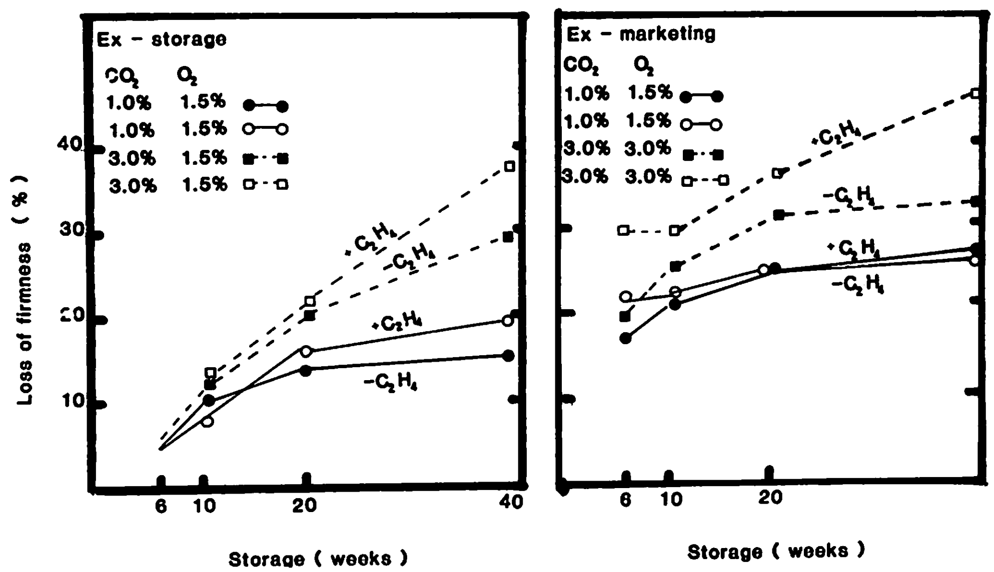

Fig 4 The effect of high ethylene during storage on the softening of Jonathans harvested at optimum maturity for long term storage. (Initial O_2 stress preceeded CA storage).

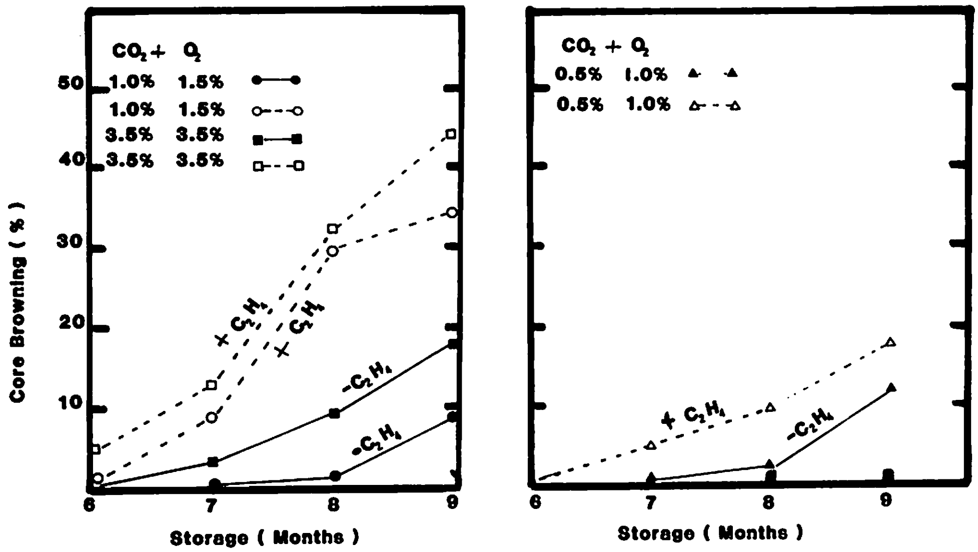

Fig 5 The incidence of core browning on Granny Smith apples, associated with high ethylene during conventional CA ULO and HLO storage. (Storage was not preceeded by initial O_2 stress)

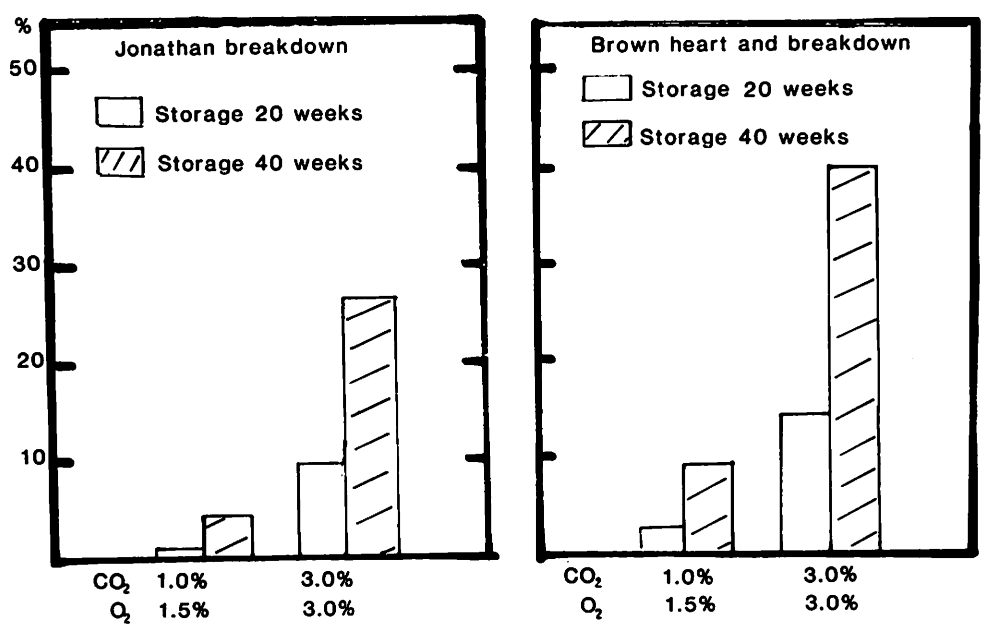

Fig 6 The increase in breakdown and brown heart on Jonathans harvested at optimum maturity which was associated with storage in conventional CA rather than ULO storage. (Initial O_2 stress proceeded conventional CA and ULO).

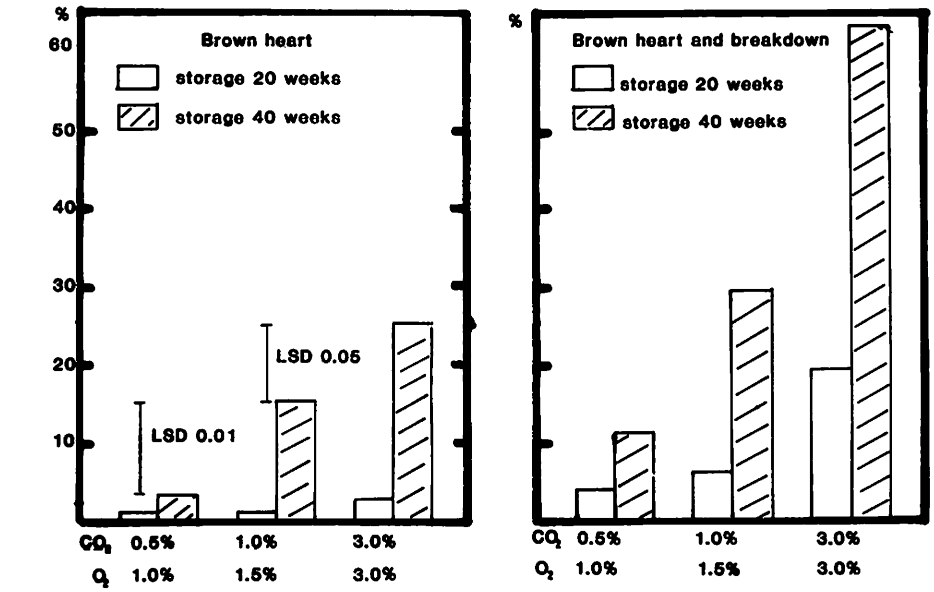

Fig 7 The effect of ULO and HLO storage techniques compared to conventional CA on the reduction of brown heart and breakdown of overmature Jonathans. (Initial 0_2 stress preceeded storage).

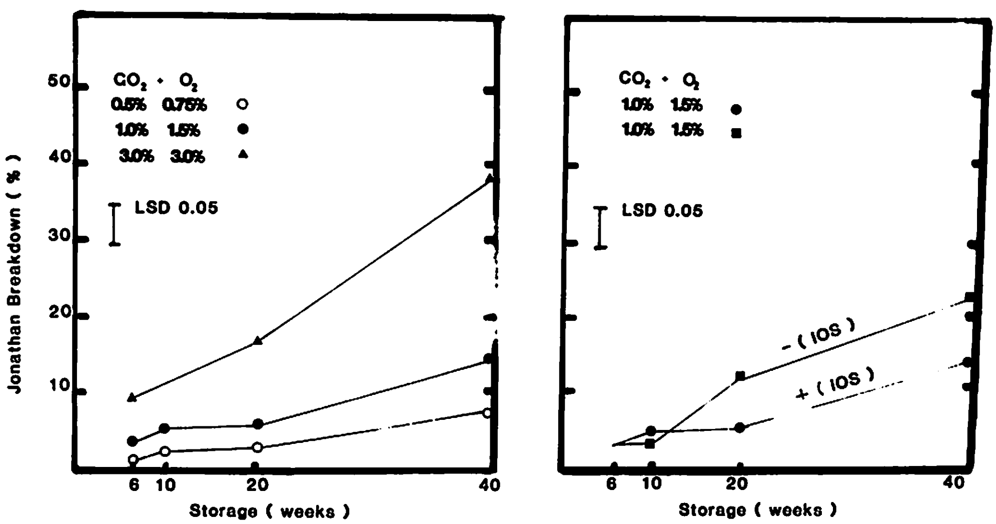

Fig 8 The relative benefits of conventionalCA, ULO and HLO storage and of IOS treatment preceeding ULO on breakdown of over mature Jonathans

TABLE 1
The effect of CA storage atmosphere on wholesaler response to apple quality during mid and late season marketing.

CA treatment	Wholesaler reaction: Jonathan mid-season	Jonathan late season	Granny Smith mid-season	Granny Smith late-season
Convential Yellow.	No comment	Excessive disorder Stock carryover	No comment	senescent scald
ULO	Crisp	Want more	No comment	Green. No disorder, want more
IOS + ULO +	Crisp	Want more	No comment	Green. No disorder, want more
HLO	Crisp	Sweet flavour	No comment	Reliable want more