QUANTUM ADVANCES IN THE COLD STORAGE MAINTENANCE OF PLUM FRUIT QUALITY USING SMARTFRESH^{SM} COMBINED WITH OTHER HANDLING AND PACKAGING CHANGES

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Introduction

According to Dodd *et al*. (2010) plum volumes increased from 1.05 m cartons in 1983, to 8.9 m cartons in 2007. With the ever-increasing volumes, the challenge has been to store plums for longer periods, while still achieving optimum quality fruit. Research on plums in South Africa therefore focussed on quality maintenance and extension of cold storage and is the basis of the current handling and cold storage protocols. Recent significant advances made to improve the quality and extend the cold storage period of plums, with the main focus on Songold, will be discussed in this communication. To understand how revolutionary these recent advances are, which have been made possible through the use of SmartFresh^{SM} technology, a brief overview of the history of post-harvest research on plums South African fruit industry is provided as introduction.

Historic post-harvest research

In 1933, the first research report on the problem of mixed maturities and internal disorders in export plums was published (Davies *et al*., 1933). After an interruption in research caused by World War II, Boyes and De Villiers (1949) developed the concept of dual-temperature storage to improve the quality of plum cultivars prone to develop internal disorders when cold stored at a –0.5^{o}C single-temperature regime. While research continued on storage temperatures, it was not until 19 years later, when the importance of accurate maturity indexing for harvesting of plums was highlighted (De Swart and Redelinghuys, 1968). This led to the creation of maturity standards for all plums cultivars (Visagie and Eksteen, 1981), a practice, which is still applied for all cultivars today.

In 1982, internal breakdown in export Songold plums was a huge problem (Eksteen, 1982). This initiated a drive in internal disorder research that continued until approximately 1994. Dodd (1984) and Kotze *et al*. (1989) were amongst the researchers who studied the influence of mineral nutrition on internal breakdown, and made recommendations aimed at improving storage quality. Van Zyl *et al*.

(1987) evaluated the fruit coating called Semperfresh® to determine if this could be used to limit the disorder, but with no success. Hartmann *et al*. (1988) established that immature plums are more prone to internal breakdown than plums harvested at a more advanced maturity. In addition, they reported that Songold plums should be stored at dual temperatures rather than at low single-temperature regimes. Commercial implementation of these research findings in 1988 significantly reduced the internal breakdown problem, but did not eliminate it. This improvement assisted in increasing the volume of export plums and in turn, necessitated extended storage to prevent an over supply situation created by a late season peak in the volume of Laetitia, Casselman and Songold. Hence, research was conducted on controlled atmosphere storage of plums (Truter *et al*., 1994). While good results were achieved in the laboratory, the commercial experiences in shipping plums in controlled atmosphere containers, combined with the release of new late season cultivars, resulted in termination of the use of this technology.

After solving the internal breakdown problem in Songold plums, a different internal disorder called gel breakdown became evident in 1991. As with internal breakdown, an urgent solution was required to ensure continued marketability (Taylor *et al.*, 1993b), and a concerted research effort was again launched to find a means of control. It was established that unlike internal breakdown, gel breakdown could not be eliminated by changes to storage temperatures (Taylor *et al*., 1993a). It was however determined that plums harvested more mature were more susceptible to gel breakdown, and that flesh firmness as opposed to total soluble solids should be used for accurate determination of optimum harvest maturity. Given that Songold plums harvested immature were prone to develop internal breakdown, while advanced maturity fruit were prone to develop gel breakdown, it was evident that Songold should to be harvested within a stringent optimum maturity window to achieve for optimum storage potential.

Despite all the research to date, sporadic internal quality problems still occurred on export plums, sometimes with severe financial loss implications. Based on work initiated by Combrink and Visagie (1997), research on effective time and temperature management was continued on the impact of delay periods between harvest and onset of forced-air cooling (Jooste *et al*., 2002), as well as rate of forced-air cooling (Khumalo *et al*., 2006). It was found that different plum cultivars vary in their sensitivity to time and temperature profiles. From a forced-air cooling point of view it was evident that slower cooling between 24 and 48 hours was safest, since many cultivars have a tendency to develop severe internal disorders, which become evident after storage, particularly following pre-harvest stress conditions such as heat waves, if cooled too rapidly.

Recent post-harvest research

In recent years, discerning international export markets have increasingly demanded perfection and reliability in the quality of fruit purchased. The costs associated with trying to achieve this high standard, combined with a challenging economic environment, make it crucial to achieve the highest possible payments for export fruit. Consequently, when dealing with highly perishable products such as plums, striving for perfection in quality maintenance remains a priority. Therefore, when AgroFresh Inc. requested ExperiCo to conduct research on SmartFresh^{SM} on South African plums, in 2001, it was deemed an important opportunity to further advance plum storage and handling technologies. Based on research on pome fruit, it was felt that SmartFresh^{SM} had potential to further lower the risk of internal disorders such as internal breakdown, gel breakdown, bladderiness and overripeness. An added potential benefit would be to commercialise a technology capable of extending the storage duration of plums, which has been a major challenge for so long.

SmartFresh^{SM} is the trade name for the ethylene inhibitor, 1-methyl-cyclopropene (1-MCP), which can reduce the rate of ripening of many horticultural products (Crouch *et al*., 2005). It was registered for use on apples in South Africa in 2002. Shortly thereafter, ExperiCo completed the registration trials for the use of SmartFresh^{SM} on Songold plums in 2003. SmartFresh^{SM} is typically applied in gas form to fruit in bulk bins in air-tight cold rooms, or to packed fruit in air-tight shipping containers or rooms. Various aspects of the effect of SmartFresh^{SM} on Songold plums were studied. These included SmartFresh^{SM} concentrations, application temperatures, application duration, application time, harvest maturity and cold storage temperatures.

In the initial stages of testing, SmartFresh^{SM} exerted such a strong inhibition effect on Songold ripening during cold storage, that the challenge was to stimulate sufficient ripening to provide both good physiological as well as eating quality. While this posed quite a challenge, it was felt that the obvious beneficial effects in controlling internal disorders justified persistent continuation of the research.

To achieve good eating quality at the end of storage, it was initially decided to restrict use of SmartFresh^{SM} to Songold plums harvested at an advanced maturity, comprising flesh firmness between 4.5 and 6.5 kg and total soluble solids higher than 14%. While this worked well in the first semi-commercial export consignments, it soon became evident that this harvest maturity window was to narrow for practical application across the fruit industry. Consequently, modified dual-temperature storage regimes were evaluated to establish if incorporation of a longer warming period than the commercially used 7 to 10 days at 7.5^{o}C, would give satisfactory ripening of Songold plums harvested within the standard industry maturity protocol, namely between 5.0 kg and 7.5 kg, or up to 8.0 kg with total soluble solids higher than 13%. It was speculated that this treatment may enable sufficient softening of the fruit over storage time, and at the same time, stimulate the reduction of acids levels to achieve acceptable eating quality.

The results generated through the research were positive. It was evident that relative to the non-SmartFresh^{SM} treated commercial controls stored at standard dual temperature, the SmartFresh^{SM} in combination with an extended warming gave far superior overall fruit quality (Table 1). While the levels of internal disorders varied in the control fruit from other populations, the trend in these fruit was similar.

Table 1: The effect of SmartFresh[SM] and duration of the warming phase at 7.5°C during dual-temperature storage on the quality of Songold plums after cold storage for 42 days followed by a shelf life of 7 days at 10°C, with the warming phase commencing after an initial 10 days at –0.5°C

Treatment		Fruit Quality[1/2]								Total internal disorders (%)
SmartFresh[SM]	Days at 7.5°C	TSS	MA	Flesh firmness (kg)	Decay (%)	Shrivel (%)	IB (%)	GB (%)	OR (%)	
No (control)	10	14.2	0.96a	0.8a	1.3	17.0ef	0.0a	75.0a	15.0bc	90.0f
Yes	10	14.1	1.21bcd	3.1e	0.7	19.0ef	15.0c	6.0b	0.0a	21.0cd
Yes	14	13.9	1.34ef	3.5ef	0.0	13.0cde	0.0a	0.0b	0.0a	0.0a
Yes	18	13.9	1.34ef	3.4e	0.0	7.5abc	0.0a	0.0b	0.0a	0.0a
Yes	22	13.8	1.50g	3.1e	1.9	16.0def	0.0a	0.0b	0.0a	0.0a
Yes	26	13.8	1.31def	2.4d	1.2	3.1ab	0.0a	0.0b	0.0a	0.0a
Yes	30	13.6	1.21bcd	1.6c	2.8	6.0abc	0.0a	1.0b	9.0abc	10.0abc
Yes	32	13.6	1.23bcd	1.5bc	0.0	3.1ab	0.0a	2.0b	7.0ab	9.0ab

1. TSS = Total soluble solids; MA = Tritratable malic acid; IB = Internal browning; GB = Gel breakdown; OR = Overripeness
2. Data analysed using One-Way Anova with significant differences across rows (P<0.5)

Using a total storage time of 42 days followed by a 7 day shelf life, extended warming periods between 10 and 32 days at 7.5^{o}C were tested, with the warming commencing after an initial 10 days at –0.5^{o}C, which simulated the holding period in South Africa prior to export. The data showed that at the end of shelf life, SmartFresh^{SM} gave firmer fruit and significantly less internal disorders with a warming period of 14 days or longer (Fig. 1). Based on these results it was decided to use a warming period between 14 and 18 days as part of SmartFresh^{SM} protocol for Songold plums. Decisions on the exact time to use within this range can be made based on the characteristics of the fruit and intended marketing strategy. It was also evident from the good results achieved in this study, that this combination treatment will also be effective in extended storage duration. This has now been tested commercially on a number of occasions, and it appears that generally, storage can be increased from 6 to 8 weeks as long as fruit with good inherent quality has been used for this purpose.

While shrivel was not increased by SmartFresh^{SM} and the extended dual-temperature warming (Table 1), the levels exhibited on this fruit as well as the untreated control fruit detracted from the perfect quality requirement, and hence, shrivel control became a new research focus area. While there was concern that a longer period at 7.5^{o}C may exacerbate decay, this was not always the case. Commercial trials conducted at a later stage clearly indicated that decay problems were linked to pre-harvest and packing decay control measures (data not shown). Furthermore, it was reconfirmed that during SmartFresh^{SM} application, it is imperative that all fruit in the treatment facility is within the harvest maturity window. This is important because once fruit has started producing the ripening hormone ethylene, which binds into receptor sites, SmartFresh^{SM} can no longer exert its full effect because the receptor sites are already blocked by ethylene.

Figure 1 : Internal appearance of SmartFresh^{SM} treated Songold plums after arrival in Europe

To solve the acceptable but still undesirable shrivel tendency on Songold, trials involving the use of wrappers and bags with different perforation configurations were tested on SmartFresh^{SM} treated fruit stored using an 18 day warming period (Table 2). The objective was to significantly reduce shrivel without causing the internal disorder problems known to occur on Songold plums not treated with SmartFresh^{SM} and stored in liners. It was established that that 48 x 4 mm perforated wrappers reduced shrivel effectively compared to Songold packed with no-liners (Fig. 2) but that 54 x 2 mm perforated grape bags gave even better control (Fig. 3), with an approximate 85% reduction in shrivel. Thus, the objective was achieved, and this improvement, for the first time enables consistent delivery of perfect internal and external quality Songold plums with the potential to be cold stored for extended periods.

Table 2 : The effect of a perforated wrappers and bags on shrivel control of SmartFresh^{SM} treated Songold plums sourced from two growers, after export to Europe using an 18 day extended warming phase dual-temperature regime and a shelf life of 5 days at 8°C

Grower	**Shrivel (%) per treatment[1]**		
	No liner	**Perforated wrapper**	**Perforated bag**
1	26.7b	20.7bc	4.0d
2	60.7a	22.7bc	9.3cd

1. Data analysed by Two-Way Anova for a significant interactive between Factor A (grower) and Factor B (treatment) ($P<0.5$)

Figure 2 : Shrivel on SmartFresh^{SM} treated Songold plums packed without a perforated wrapper or bag liner after arrival in Europe

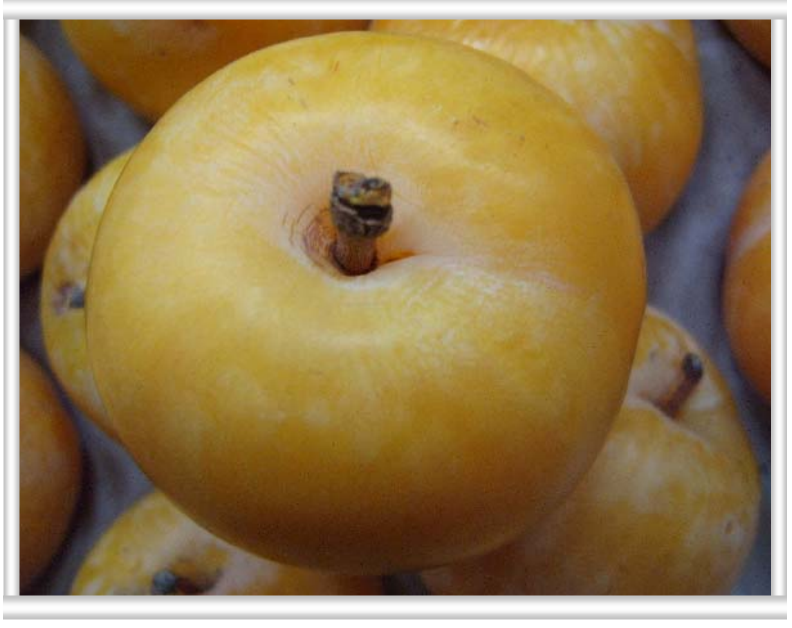

Figure 3 : Unshrivelled SmartFresh^{SM} treated Songold plums packed with a perforated bag liner after arrival in Europe

Current status

To date, the registration for use of SmartFresh[SM] on plums has been restricted to Songold. Since the initial registration, further research has been conducted on other cultivars including: Pioneer, Sapphire, Larry Ann, Sundew, Laetitia and Angeleno. Based on these efficacy trials, an application has been made for a broad based plum registration which will hopefully be in place in the near future. This research has indicated that the benefits derived from use of SmartFresh[SM] will vary on a cultivar basis and that the storage temperature requirements vary between cultivars. In addition, ongoing studies will be required to perfect the peripheral technologies that, collectively, enable - Quantum Advances!

To summarise, the current SmartFresh[SM] protocol for Songold plums states that the flesh firmness must be between 5.0 and 7.5 kg, with the optimum 6.5 kg, as measured using a penetrometer with a 11.3 mm plunger. It is also important that maturity of the fruit should be uniform, with no plums below a minimum flesh firmness of 5.0 kg and with total soluble solids level higher than 12.5%. The SmartFresh[SM] must be applied to Songold plums in cold storage with 7 days of harvest for packed fruit, and within 5 days of harvest for fruit in bins. For SmartFresh[SM] treated Songold, packed in standard cartons, perforated grape bags (54 x 2 mm perforations) or perforated plum wrappers can be used. Only use the perforated bags on SmartFresh[SM] treated Songold plums ! The warming cycle at 7.5°C during dual-temperature storage is to be between 14 and 18 days in duration depending on rate of ripening, and thereafter, cold storage at –0.5°C is prescribed. The maximum storage period from harvest is 56 days, excluding shelf life. As is often the case, inherent fruit quality will influence outturn quality. Hence, it is important to monitor quality during storage, so that appropriate decisions can be made to ensure perfect quality.

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