Project title	**Tomatoes: preliminary investigation of the effects of cultivar, stage of harvest and post-harvest storage on fruit lycopene content**
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PRACTICAL SECTION FOR GROWERS

Background and Objectives

A number of major diseases, including cancer and heart disease, may be initiated by cell damaging molecules called free radicals. Research has shown that the incidence of these diseases may be reduced by the consumption of fruits and vegetables. This is because of their *antioxidant* components, which have the ability to neutralise or *quench* free radicals.

Antioxidants include vitamins A, C and E and carotenoids, all of which are found in tomatoes. Lycopene, the red pigment in tomatoes, is a carotenoid. It has been found to be a particularly effective antioxidant. About 85% of lycopene in typical western diets is derived from tomatoes.

Fruit lycopene content may become an important consideration in tomato product quality or specification and provide an opportunity to promote tomato consumption.

The main aims of the project are to provide information on the range and variability of fruit lycopene content according to cultivar, production location and harvesting treatment and to make comparisons with imported fruit and processed tomato products.

This information should help to:

- identify individual tomato products which may provide a particular benefit to consumers, and therefore a marketing opportunity for producers.
- indicate those treatments which may optimise or maintain lycopene content.
- clarify previous comparisons between processed and fresh tomato products.
- provide particular opportunities for the promotion of British tomatoes.

Summary of Results

Harvesting stage and storage

Fruit harvested at colour stages 1, 5 and 9 (as judged by visual assessment using the Dutch tomato colour chart *Kleur-stadia tomaten*) showed an eight-fold increase in lycopene content, from 5 to 40 mg/kg on a fresh weight basis, over this colour range. Treatment effects were similar for both the classic cultivar Espero and the cherry tomato Favorita.

Storage of fruit for 7 days at ambient, after reaching colour stage 9, resulted in a further increase in lycopene content, to a level around 12 times that at colour stage 1.

There was little difference observed in the lycopene content of fruit ripened on or off the plant. It should be noted however, that fruit ripened off the plant was stored under ambient conditions in this project, not in cool or cold storage.

The highest lycopene concentrations found in the project were up to three times previously quoted figures for fresh tomatoes. In *The Role of Lycopene and Tomatoes in Disease Prevention* (publication sponsored by H J Heinz), a figure of 30 mg/kg is quoted for raw tomato. Results confirm that this figure is similar to levels commonly found in classic tomato cultivars marketed at typical levels of maturity, but considerably less than the potential for such varieties.

Effects of cultivar and product type

Samples of 13 cultivars from UK nurseries were analysed on three separate occasions. Three samples each of a cultivar from mainland Spain and a cultivar from the Canary Islands were analysed. In each case the fruit was from the same source.

Fresh tomato samples were sought as near to the same colour stage as possible (stage 9) for analysis. In practice this is somewhat difficult because of natural variations in pigmentation between cultivars; in accurately assessing fruit colour by eye whilst fruit is still on the plant; and in obtaining similar samples when assessed by different producers. Some of the differences observed between treatments may have been due to these sources of variation.

There was a wide range in lycopene content between cultivars, from 37 to 82 mg/kg for red varieties. Not surprisingly Golden Cherry was very low, this variety being gold rather than red, when ripe.

The speciality beefsteak cultivar produced the highest figure at 82 mg/kg. This cultivar is not only deep red externally when ripe, but appears visually to have more red pigment internally when cut.

Other high figures were obtained for the truss varieties Aranca (67 mg/kg) and plum types Baby Sweetheart (64 mg/kg), Santa (71 mg/kg) and Yolande (74 mg/kg).

Whilst three samples each from Spain and the Canary Islands cannot in any way be considered as representative of production there, the lycopene content for these types was consistently low at around 17 mg/kg, only about one third of similar sized UK fruit. Spanish fruit of this type has a noticeably orange, rather than red appearance, even some considerable time after harvest. Whether this is connected to long-life characteristics is not known.

Three processed tomato products were also analysed. These were Heinz Tomato Ketchup (174 mg/kg), Sainsbury's Tinned Plum Tomatoes (106 mg/kg) and Sainsbury's Tomato Puree Double Concentrate (508 mg/kg).

The lycopene content of tinned plum tomatoes did not greatly exceed the highest levels found in fresh products. At a retail price of 9p per 400g tin, at the time of the analysis, the cost per mg lycopene is very low however.

Lycopene intake in the diet depends not only on the concentration in individual products but on the size of servings of these products. A 10ml serving of Heinz Tomato Ketchup (the typical serving suggested on the bottle) would contain 1.74 mg lycopene. This is less than half that which would be contained in 5 cherry tomatoes such as Santa (5.00 mg), and less than one sixth of that in one fruit of the beefsteak variety tested (12.35 mg).

Fresh tomatoes were not cooked as part of this project. It would be of interest to do this, to test the effect on lycopene concentration.

In comparing the benefits of fresh tomatoes with processed products, it should be noted that fresh tomatoes contain a number of beneficial ingredients other than lycopene, some of which may be degraded by cooking.

Location of production

Samples of the variety Espero were obtained from 10 different producers throughout the country, on the same date on each of three occasions in August, September and October. Fruits were harvested at the same colour stage (5) and tested at colour stage 9.

No effect of location on lycopene content was discernible from the results and there was no identifiable influence of latitude. There was considerable variation between the three individual replicates from some sites, whilst others were more consistent. This almost certainly reflects the consistency of sample selection, rather than a causative effect due to location.

The average result (32 mg/kg) is in line with those for Espero picked at colour stage 5 and ripened off the plant to stage 9, in the first part of this project and with previously published data for raw tomatoes. It is considerably less than the potential figure in more mature ripe fruit.

Action Points For Growers And Practical And Financial Benefits

- Strong opportunities exist to promote the benefits of fresh tomatoes for their lycopene content and other associated health attributes.

- Market research is needed to quantify whether there are potential benefits to be gained in attracting premium prices for high lycopene tomatoes.

- It is possible, by varietal selection, appropriate fruit storage and marketing of more mature fruit, to offer tomatoes with considerably higher lycopene content than many currently exhibit.

- The successful development of truss harvested tomatoes demonstrates the opportunity to market more mature fruit, with associated benefits in flavour and lycopene content.

- There is still market prejudice against classic types supplied in a riper condition, especially when loose-packed. This is based on the perception of reduced shelf-life for more mature fruit. There is some validity in this view since there is no doubt that the handling of loose packed tomatoes, at various points in the marketing chain, leaves much to be desired. Truss harvested fruit, on the other hand, has to be handled with great care to maintain its integrity.

- Opportunities exist to promote fresh tomatoes more effectively, compared with processed products, on the basis of their lycopene content and other benefits, than has previously been thought to be the case. Processed products are often very cheap however.

- These results suggest an opportunity to promote UK fruit compared with southern European products, at least of classic types, because of higher lycopene levels. Further research is needed because of the limited number of imported samples tested in this project.

- Research is needed to check whether storage periods longer than 7 days will result in yet higher lycopene content, to establish the peak for fresh tomatoes and, if so, whether this is accompanied by reduced palatability of fruit. Research is also needed to test the effects of storage at lower temperatures than ambient and to investigate the effect of cooking, on the lycopene content of fresh tomatoes.

SCIENCE SECTION

Background and Objectives

a). Diet and health

It has long been recognised that diet is a crucial factor in promoting human health and avoiding disease. Research shows that one third of cancer cases are related to what we eat [(1)]. Prevention of cardiovascular disease (heart disease, artherosclerosis and cerebrovascular disease) is also strongly associated with a healthy diet, together with a healthy lifestyle.

In the UK alone, two thirds of all deaths are caused by cardiovascular disease and cancer, so there is great potential for reducing premature death through dietary change.

The food we eat can affect our health in many ways. In particular it may contain beneficial ingredients, which promote good health and protect us against disease, or it may contain harmful constituents which increase the risk of disease, or cause damage to our bodies.

It follows that the healthiest foods are those that combine the maximum amount of beneficial ingredients with minimal harmful or toxic constituents. Among the foods known to be particularly healthy are fruit and vegetables. Tomatoes have been found to contain several potentially beneficial ingredients.

Foods which are regarded as particularly good for health are sometimes referred to as *functional* foods. These are defined as: "Any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains." (*US Institute of Medicine, 1994*). Tomatoes, according to this definition, are valuable functional foods.

Recent medical research has concluded that free radicals may play a part in many major diseases, including cancer and cardiovascular disease, age-related blindness, arthritis and even the ageing process itself. These gene-damaging molecules arise naturally but also commonly act as environmental pollutants in, for example, exhaust fumes and cigarette smoke.

In addition to the body's own defence mechanism to deal with free radicals, research has shown that the risk of developing some major diseases may be reduced by increased consumption of fruits and vegetables [(2, 3)]. This is because of their *antioxidant* properties, their ability to neutralise or "quench" free radicals.

Antioxidants include vitamins A, C and E, carotenoids and flavonoids. Tomatoes contain all of these ingredients.

b). Carotenoids and lycopene

Carotenoids are a group of some 600 naturally occurring pigments of which about 40 are consumed by humans. They are synthesised in plants. One of the best known carotenoids is β-carotene, found in highly coloured fruit and vegetables such as carrots, peppers and tomatoes. In the body, carotenoids are converted to vitamin A, which may offer cancer protection because of its role in normal cell differentiation.

The most obvious alteration in tomato fruit during ripening is the change in colour from green to orange to red. This colour change is primarily brought about by the transition of chloroplasts into chromoplasts with the synthesis of specific carotenoids and some flavonoids. As ripening begins, chlorophyll degradation accelerates and the thylakoids and starch grains are broken down. The characteristic foliar cartenoids found in green fruit, i.e. lutein, neoxanthin, and violaxanthin, decreases while new pigments such as ß-carotene and lycopene accumulate in the plastids. ß-carotene reaches peak concentrations early during ripening and is responsible for the orange colour of tomatoes. Lycopene production occurs slightly later and causes the fruit to appear red.

The long chain molecular structure of lycopene makes it a particularly effective antioxidant [4, 5]. In laboratory studies, lycopene has been found to be a more potent inhibitor of human cell cancer proliferation than either α-carotene or β-carotene. It has been shown to be more than twice as effective as β-carotene in protecting human lymphocyte cells (white blood cells) from the damaging effects of nitrogen dioxide, for example [6]. Nitrogen dioxide is a common air pollutant, which is also found in high concentrations in cigarette smoke.

Several studies have indicated reduced levels of digestive tract cancers with high tomato consumption and/or lycopene blood serum levels [7]. High consumption of lycopene from tomato-based foods is associated with reduced cancer risk at several sites, but especially the stomach, colon and rectum.

A number of studies have indicated an association between high intake of tomato products and reduced prostate cancer risk in men [8]. Prostate cancer accounts for 14% of male cancer cases in the UK.

A recent review looked at 72 separate studies on lycopene and health from around the world. Fifty-seven reported inverse associations between tomato intake, or blood lycopene level, and the development of various cancers and the results of 35 studies were statistically significant. Evidence was strongest for cancers of the prostate, lung and stomach.[9]

In a Europe-wide study on cardiovascular disease, comparing men who had suffered heart attacks with healthy men, it was found that those with high levels of lycopene were only half as likely to have an attack as those with low lycopene. Two other carotenoids studied showed little or no effect [10].

Recent studies on the exposure of the skin to ultraviolet (UV) radiation have shown a marked and rapid reduction in skin lycopene levels with exposure, but no reduction in beta-carotene [10, 11]. This suggests that lycopene may be active in protecting the skin from UV damage from sunburn. This is an increasing cause of skin cancers, such as malignant melanoma, associated with increased exposure of the skin to sunlight.

A number of other diseases may also be affected by lycopene ingestion. Recent studies have shown low levels of serum lycopene in children infected with HIV, both at the non-AIDS and AIDS stages of the disease [12]. The clinical implications of this result require further evaluation.

Age-Related Macular Degeneration (ARMD) is the most common form of blindness in the western world. Lycopene is the only micro-nutrient whose serum level is inversely related to the risk of ARMD i.e. the higher the level the lower the risk. Since there is no lycopene in the eye, this is a surprising result, which is not yet understood [13].

In summary, there is a wide variety of evidence that the consumption of lycopene from tomato products shows great promise in reducing the onset of several specific diseases, including heart attacks and several cancers.

More detailed epidemiological studies of lycopene and fundamental chemical and biological research are needed to establish the direct health benefits and to clarify the complex mechanisms at work.

Additionally, many of the studies have related the consumption of tomatoes, or tomato based products in the diet to health, rather than the intake of lycopene per se. It is important therefore, to quantify the lycopene content of different tomato products, to be able to relate their consumption to lycopene ingestion and health.

c). Other beneficial food ingredients in tomatoes

Flavonoids are a group of chemicals found in some plant tissues in relatively high concentrations. Individual flavonoids tend to have a restricted distribution in the plant kingdom, many appearing in only one genus or even species.

Within the group, *flavonols* and *flavones* are of particular importance as they have been found to possess antioxidant and free radical scavenging activity in foods [(14)]. Studies have indicated that their consumption is associated with a reduced risk of cancer and cardiovascular disease [(15, 16)].

Vegetables, fruits and beverages are the main dietary source of flavonoids [(17)]. Tea, red wine and tomatoes are important, depending on the relative amounts consumed in individual diets.

Tea is one of the main sources of flavonoids for adults in the UK but its limited use by younger people is declining in favour of carbonated drinks and coffee, which are relatively low in flavonoids.

Red wines are a major source of flavonoids in countries where consumption is high, such as Italy and France. Coupled with a high consumption of tomatoes and relatively little saturated fat, this may be one of the factors which makes the "Mediterranean" diet a particularly healthy one.

It is known that the processes leading to coronary heart disease and cancers are initiated many years before the diseases manifest themselves. Since children consume relatively little tea or red wine, the consumption of fruit and vegetables high in flavonoids and other potentially protective constituents is critical to their future health.

Cherry tomatoes have a higher flavonoid content, pound for pound, than larger fruited types [(17)]. Since cherry tomatoes may be more appealing in flavour and size to children than larger tomatoes or other salads and vegetables, they could represent an important dietary benefit for youngsters.

Minerals are important for cell metabolism, good health and growth. Tomatoes contain a high level of potassium, which is important for healthy blood, together with calcium and other mineral salts and trace elements.

Dietary fibre is important to maintain a healthy digestive system and may also help to control high cholesterol levels in the blood. Tomatoes are a good source of fibre, especially when eaten with the skin and seeds.

d). Food supplements versus fresh foods

The promise of antioxidants as possible anti-cancer supplements has failed to materialise in a number of clinical trials where, for instance, daily β-carotene supplements were administered to patients who included smokers, former smokers and workers exposed to asbestos [(18)].

Not only was the incidence of disease not reduced in these trials, there was evidence that the death rate and cancers were increased where patients received the supplement. More recently, significantly more deaths from fatal coronary heart disease were noted in the β-carotene supplemented group [(19)].

The precise reasons for this effect are not known, but one reason may be that there are interactions between different antioxidants, through which they may be mutually regenerated, after having "absorbed" free radicals [20, 21, 22]. A balance or range of different protective constituents in food may therefore be important.

No clinical trials have been conducted to compare the health effects of taking lycopene supplements with lycopene derived from consumption of tomato products. In one trial,[23] lycopene levels in blood plasma were similar whether from tomato juice or lycopene supplements, but it cannot be assumed that the health benefits are similar.

Lycopene, like other carotenoids, may only be beneficial as a result of interactions with other antioxidant molecules present in tomatoes. Using lycopene by itself, as a single micro-nutrient supplement, may not be as beneficial [24].

e). Cooked versus uncooked tomatoes

There is evidence that cooking tomatoes can increase the absorption of lycopene into body tissues [25]. Cooking tomatoes in certain oils, such as olive oil, is also believed to help this process. This is another reason why a Mediterranean diet may be a healthy one.

Processing tomatoes into more concentrated forms will also increase the lycopene concentration but some processed products, such as canned tomatoes, have additives such as salt, which may represent a less desirable feature.

Cooking tomatoes is likely to reduce the content of some beneficial ingredients, such as flavonoids [17], vitamin C and vitamin E. The fibre content may also be affected, especially if the skins are discarded in cooking. Since tomato consumption in the UK is relatively low compared with other European countries, it makes sense to recommend increased consumption of both fresh and cooked tomatoes. Cooked, fresh tomatoes could be particularly beneficial.

The lycopene content of fresh tomatoes is known to vary with the variety, the stage of ripeness at harvest and storage conditions [26]. Figures quoted by manufacturers of processed tomato products do not specify the origin of fresh tomatoes used in comparisons.

f). What tomatoes do not contain

Tomatoes are very low in calories, typically only 10-15 kcals for a medium size fruit (65g). Tomatoes contain virtually no fat.

Excess salt (sodium chloride) consumption represents an increased health risk. Reduced sodium intake is recommended as one of the ways to reduce the incidence of heart disease and stroke. There is a lot of "hidden" sodium in the diet in fast foods, prepared foods and those with preservatives.

Fresh tomatoes have a low sodium content. That in canned tomatoes may be 30-40 times higher because of the addition of salt.

The range of beneficial ingredients in tomatoes, especially antioxidants such as lycopene, coupled with a low calorie and negligible fat content, makes tomatoes one of the most valuable additions to the human diet. The interest in these aspects, and the potential to exploit them, are the main factors prompting this research.

Recent publicity sponsored by manufacturers such as H J Heinz, has promoted the benefits of processed tomato products, for their lycopene content, in comparison with the fresh or raw fruit. No information has been given in this material to the source or selection of the fresh product, in terms of cultivar, stage of ripeness or production system, all of which may have a considerable impact on actual lycopene content.

Other studies, such as those on flavonoids,[17] can be criticised for using non commercial cultivars in their research. Published results also lack details of the maturity and condition of samples tested.

It is in the interests of producers of fresh tomatoes to investigate these areas, to ensure that their products are not being misrepresented and to identify opportunities for improving and promoting these products, if such opportunities exist and are commercially attractive. This is the primary reason for carrying out this project.

The objectives of the work were to:

- Investigate the effect of stage of fruit ripeness at harvest and the effect of storage on the lycopene content of a classic and cherry type of tomato fruit.

- Identify by analysis the lycopene content of a classic tomato cultivar grown in different locations in the UK.

- Identify by analysis the lycopene content of a number of tomato cultivars and types, both home produced and imported.

Materials and Methods

a). Stage of ripeness at harvest and analysis.

Samples of cultivars Espero and Favorita were selected and harvested directly by the project leader, on the same dates in each of three months. These were in August, September and October 1999.

Samples were taken from the same plants each time and were either analysed immediately at the specified colour stage, or allowed to ripen off the plant under ambient conditions to a later colour stage. In each case the sample comprised ten individual fruits. Samples were then dispatched by courier for High Pressure Liquid Chromatography (HPLC) analysis by Natural Resource Management Ltd, Bracknell.

As an example, the schedule for sample collection and dispatch for Replicate 3 is included at Appendix 1.

Samples for cv Espero were obtained from Hazlewood VHB, Runcton Nursery, Runcton, Chichester. Samples of cv Favorita were obtained from Mr N Lee, Woodleigh Nursery, Sidlesham, Chichester. Both crops were grown in heated glasshouses in conventional rockwool systems.

b). Cultivar and product type.

Samples of all cultivars, other than Red Choice and the speciality beefsteak variety, were obtained from Hazlewood VHB, Holland Nursery, Littlehampton. All were grown in the same heated glasshouse in rockwool. Fruit was selected and harvested by Dr N O Dungey and staff and then dispatched by the project leader for immediate analysis.

Fruit of Red Choice was obtained from Arreton Valley Nursery, Isle of Wight and of the speciality beefsteak cultivar, from Mr N Lee and dispatched as above.

Spanish and Canary samples were obtained from Hazlewood VHB and selected by the project leader from commercial consignments delivered to the Hazlewood VHB Littlehampton packhouse.

Processed tomato products were purchased from Sainsbury's Chichester store on 31 August 1999.

c). Location of production.

Samples of the variety Espero were obtained from 10 different producers throughout the country, on the same date on each of 3 occasions, in August, September and October 1999.

Samples were collected and dispatched directly by growers, with a request that they were all harvested at the same colour stage. This was stage 5 i.e. fairly typical of the normal harvest stage for a classic variety.

The samples were then kept and dispatched directly to NRM Ltd, to arrive for analysis five days later, at colour stage 9.

Results

a). Stage of ripeness at harvest and analysis

Lycopene analysis results for individual sample replicates and averages of the three replicates are shown in Table 1 and Figures 1 and 2 for classic cultivar Espero and in Table 2 and Figures 3 and 4 for cherry tomato cultivar Favorita. Table 3 compares average figures for the two cultivars.

Table 1. Effects of stage of ripeness at harvest and analysis on fruit lycopene content of cv Espero

Treatment	Fruit colour stage		Lycopene content (mg/kg)			
	Harvest	Analysis	Rep 1	Rep 2	Rep 3	Mean
1	1	1	1.6	9.2	3.4	4.7
2	1	5	13.6	29.4	26.1	23.0
3	1	9	30.4	44.3	37.6	37.4
4	1	9 + 7days	45.6	65.0	48.2	52.9
5	5	5	12.3	22.6	20.0	18.3
6	5	9	19.4	44.0	38.4	33.9
7	5	9 + 7 days	46.2	71.3	54.5	57.3
8	9	9	25.7	58.0	42.5	42.1
9	9	9 + 7days	61.0	69.5	56.5	62.3

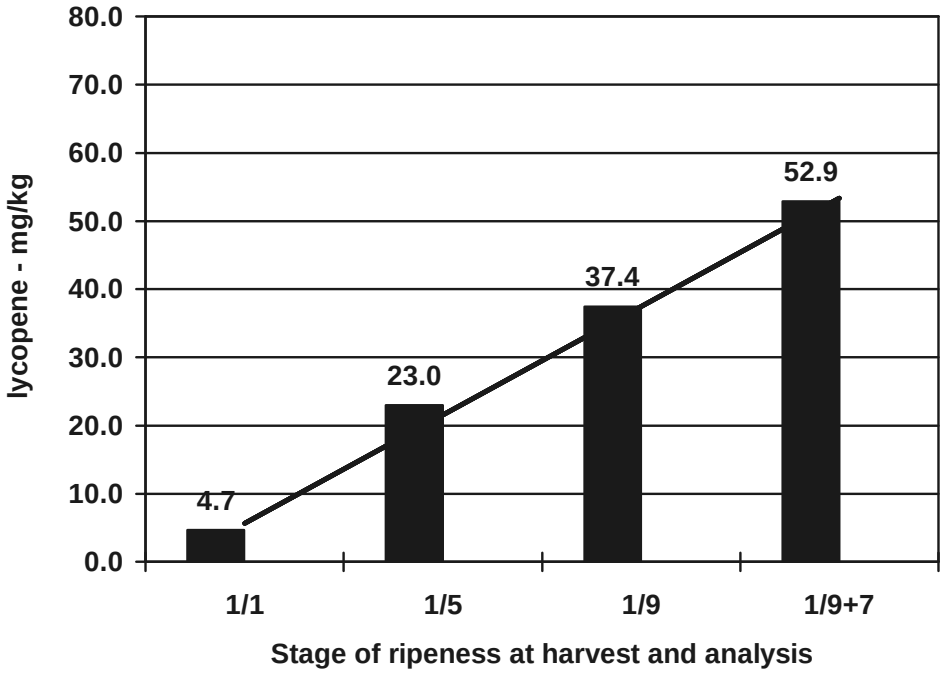

Figure 1. Effect of stage of ripeness at analysis on fruit lycopene content of cv Espero harvested at colour stage 1 and stored at ambient until colour stage 1, 5, 9 and 9+7 days

Figure 2 Effect of stage of ripeness at analysis on fruit lycopene content of cv Espero harvested and analysed at the same colour stage.

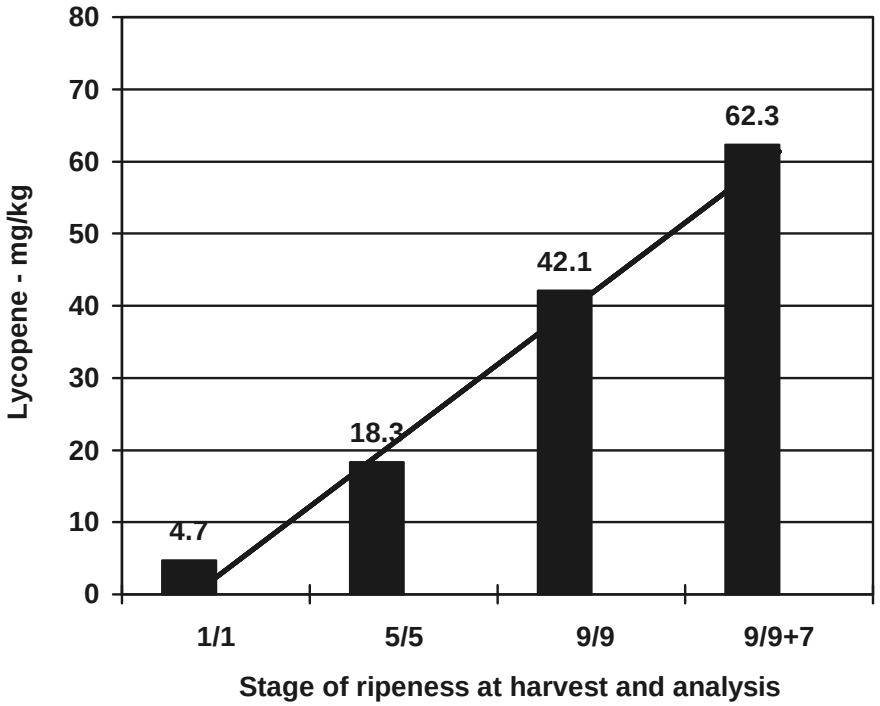

Table 2 Effects of stage of ripeness at harvest and analysis on fruit lycopene content of cherry tomato cv Favorita

Treatment	Fruit colour stage		Lycopene content (mg/kg)			
	Harvest	Analysis	Rep 1	Rep 2	Rep 3	Mean
1	1	1	2.6	5.6	5.7	4.6
2	1	5	21.9	21.9	22.7	22.2
3	1	9	34.4	37.6	40.6	37.5
4	1	9 + 7days	51.6	55.2	78.9	61.9
5	5	5	16.2	33.1	19.3	22.9
6	5	9	29.2	34.4	40.0	34.5
7	5	9 + 7 days	67.2	75.8	68.2	70.4
8	9	9	54.8	53.1	33.8	47.2
9	9	9 + 7days	63.2	67.4	108.9	79.8

Note: Underlined figure was double checked by re-analysis of sample.

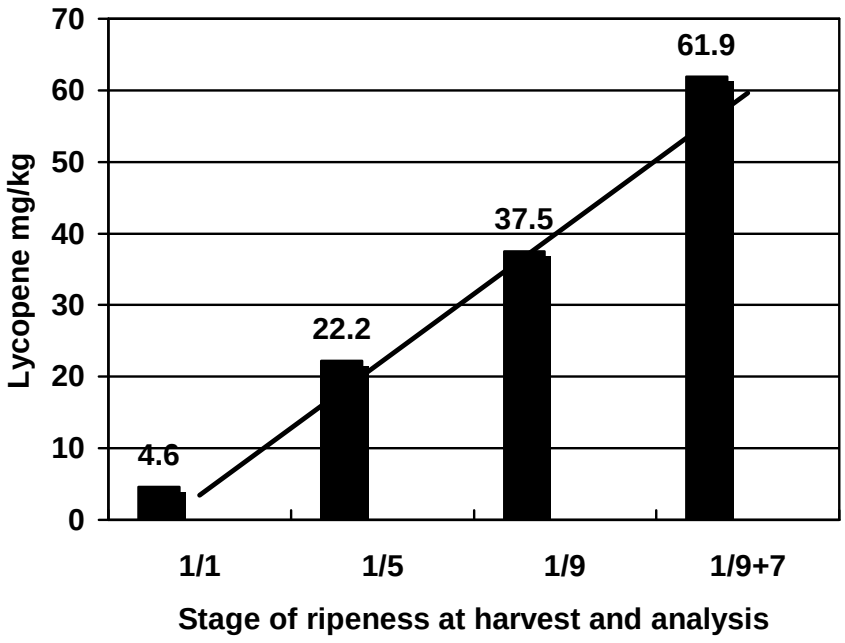

Figure 3- Effect of stage of ripeness at analysis on fruit lycopene content of cv Favorita harvested at colour stage 1 and stored at ambient until colour stage 1, 5, 9 and 9+7 days

Figure 4. Effects of stage of ripeness at analysis on fruit lycopene content of cv Favorita harvested and analysed at the same colour stage.

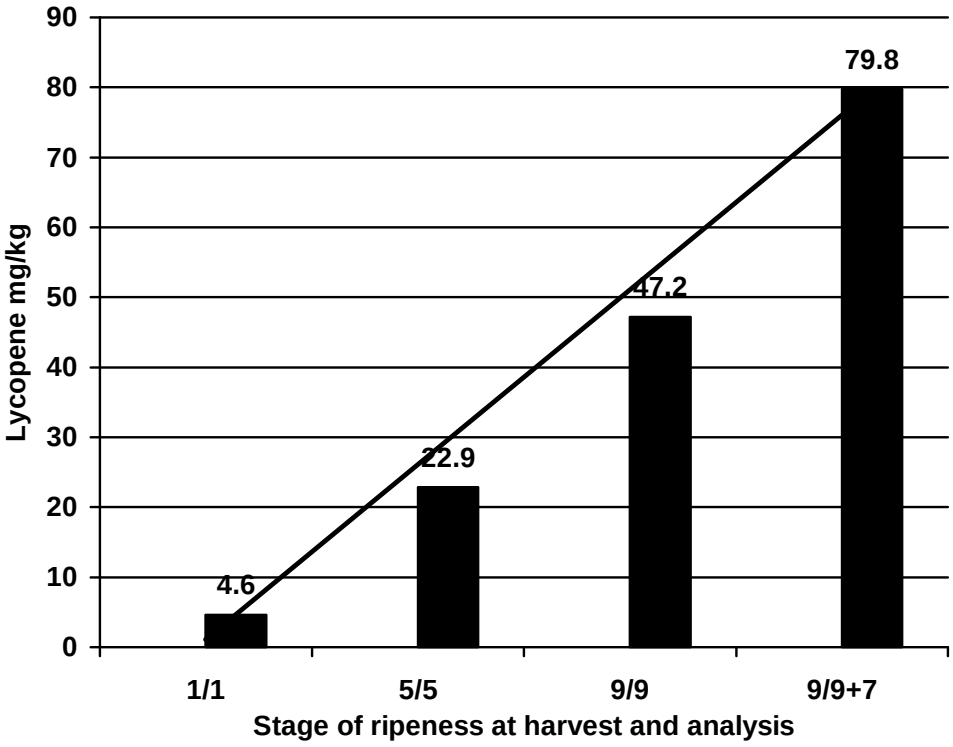

Table 3 Effects of stage of ripeness at harvest and analysis on average fruit lycopene content of cvs Espero and Favorita

Treatment	Fruit colour stage		Mean lycopene content (mg/kg)	
	Harvest	Analysis	Espero	Favorita
1	1	1	4.7	4.6
2	1	5	23.0	22.2
3	1	9	37.4	37.5
4	1	9 + 7days	52.9	61.9
5	5	5	18.3	22.9
6	5	9	33.9	34.5
7	5	9 + 7 days	57.3	70.4
8	9	9	42.1	47.2
9	9	9 + 7days	62.3	79.8

The results show similar trends for both cultivars. The major effect on the lycopene content of fruit is the stage of ripeness at analysis. The increase in lycopene over the colour stages 1, 5, 9 is more or less linear.

While there is some noise in the data, there is no evidence to suggest that the lycopene content is higher in fruits left to ripen on the plant rather than in fruits ripened in storage under ambient conditions.

One difficulty with this subject is in accurately determining fruit colour with the naked eye, especially when fruits are amongst foliage before picking. It also proved very difficult logistically to synchronise ripening of fruit on and off the plant to the same colour stage at analysis, having selected similar coloured fruit initially.

Time in transit would allow further fruit ripening and affect lycopene content as a result. Efforts were made in this project to keep this time to a minimum by overnight courier delivery to the laboratory, or at least to keep the time as constant as possible to be able to make allowances for it. Immediate processing of samples after electronically measured colour assessment and selection would increase the accuracy of research on this subject, but would add significantly to the cost of such research.

There was a substantial increase in lycopene content of both cultivars with storage for 7 days after colour stage 9. This increase was of the order of 50% for Espero and more than 65% for Favorita. Whether there would have been a further increase beyond 7 days storage, or whether storage at lower temperatures than ambient would have affected the results, is not known.

The lycopene content of cv Favorita after 7 days' storage was higher than that of Espero. It is not possible to say whether this reflects a higher potential figure for Favorita, or a faster rate of ripening over this period.

The third replicate of the treatment where Favorita was picked at colour stage 9 and analysed 7 days later (9/9 + 7 days) gave a suspiciously high result at 108.9mg/kg. The submitted sample was reanalysed and this result was confirmed. It is so different to the other two replicates as to reduce confidence in the figure however.

Fruit which were treated in a similar way to typical current commercial standards, i.e. picked at colour stage 5 and retailed at colour stage 9, produced results similar to the 30 mg/kg figure quoted in other literature for raw tomatoes. Actual figures for this treatment were 33.9mg/kg for Espero and 34.5mg/kg for Favorita.

Average weight of all Espero samples tested was 93.0g and Favorita 14.9g. From these figures the lycopene content per fruit can be calculated, in addition to the lycopene concentration in mg/kg.

b). Cultivar and product type.

Results for the 13 UK-grown cultivars tested and one each from mainland Spain and the Canary Islands are given in Table 4. Figures are also given for the three processed tomato products tested (Table 5).

Fresh tomato samples were sought as near to the same colour stage as possible (stage 9) for analysis. In practice this proved very difficult because of natural variations in pigmentation between cultivars and, as mentioned above, in accurately assessing fruit colour by eye whilst fruit is still on the plant.

There was a further difficulty with this part of the project in obtaining similar samples when assessed by different producers. For example, the sample of Red Choice (syn Campari) produced lower figures than expected. This is probably related to it being at a less advanced stage of ripeness at analysis, although efforts were made to get similar samples in this respect.

Because of the sensitivity of the analysis to stage of fruit ripeness, the results may be affected by variations in samples in this respect, especially where selection is being made by different observers. Assessment of colour by some electronic means, rather than by the human eye, would give more replicable results. Accurate assessment of colour before harvesting of fruit is particularly difficult, as mentioned elsewhere.

The results showed a wide range in lycopene content between cultivars, from 37 to 82 mg/kg for red varieties. Not surprisingly Golden Cherry was very low at 8.6 mg/kg, being gold rather than red, when ripe.

The speciality beefsteak cultivar produced the highest figure at 82 mg/kg. This cultivar is not only deep red externally when ripe, but appears visually to have more red pigment internally.

Other high figures were obtained from the truss varieties Aranca (67 mg/kg) and plum types Baby Sweetheart (64 mg/kg), Santa (71 mg/kg) and Yolande (74 mg/kg).

Results for the samples from Spain and the Canary Islands were consistently low at around 17 mg/kg, only about one third of similar sized UK fruit. Spanish fruit of this type has an orange, rather than red appearance, even some time after harvest. Whether this is connected to long-life characteristics is not known.

The processed tomato products showed generally high figures as expected. This is because of the release of lycopene from chromoplasts during processing (cooking) and the concentrating effects of water removal. Lycopene concentrations were for Heinz Tomato Ketchup 174 mg/kg, Sainsbury's Tinned Plum Tomatoes 106 mg/kg and Sainsbury's Tomato Puree Double Concentrate 508 mg/kg.

The lycopene content of tinned plum tomatoes did not greatly exceed the highest levels found in the fresh samples. At a retail price of 9p per 400g tin, at the time of the analysis, the cost per mg lycopene is very low however.

Lycopene intake in the diet depends not only on the concentration in individual products but on the size of servings of these products. A 10ml serving of Heinz Tomato Ketchup (the typical serving suggested on the bottle) would contain 1.74 mg lycopene. This is less than half that which would be contained in 5 cherry tomatoes such as Santa (5.00 mg), and less than one sixth of that in one fruit of the beefsteak variety tested (12.35 mg).

Average fruit weights for each variety are shown in Table 4. From these figures the average lycopene content in mg per fruit has been calculated, in addition to the lycopene concentration in mg/kg.

Table 4. Lycopene concentration in mg/kg and content in mg per fruit of 13 UK grown cultivars and two fruit samples imported from southern Europe.

Cultivar	Lycopene content					Weight (g)
	mg/kg				mg/fruit	
	Rep 1	Rep 2	Rep 3	Mean		
Aranca	53.1	88.5	58.9	66.8	3.07	46.0
Baby Sweetheart	51.5	77.9	61.5	63.6	2.48	39.0
Elegance	54.3	48.7	51.3	51.4	4.81	93.5
Espero	33.4	45.1	33.4	37.3	3.79	101.5
Favorita	42.4	77.6	43.1	54.4	1.39	25.5
Ferrari	37.4	63.5	54.1	51.7	4.52	87.5
Golden Cherry	9.3	4.0	12.4	8.6	0.14	16.0
Plum 6280	36.0	58.6	51.5	48.7	4.45	91.3
Red Choice (Campari)	39.7	52.2	46.8	46.2	2.94	63.5
Santa	62.2	66.9	84.4	71.2	1.00	14.0
Solairo	41.6	33.3	38.6	37.8	3.45	91.3
Yolande	65.5	73.6	82.0	73.7	6.36	86.3
Speciality beef	72.9	98.8	74.2	82.0	12.35	150.7
Calibra (Spain)	16.5	16.6	20.0	17.7	1.55	87.5
Lupema (Canaries)	13.9	18.5	16.6	16.3	1.25	76.3

Table 5. Lycopene concentration in mg/kg and content in mg per pack of 3 processed tomato products.

Product	Lycopene content		Pack weight (g)
	mg/kg	mg/pack	
Heinz Tomato Ketchup	174.0	34.8	200
JS Tinned Plum Tomatoes	106.0	42.4	400
JS Tomato Puree (Double concentrate)	508.0	50.8	100

c). Location of production.

Results for samples of Espero harvested from a number of geographic locations are detailed in Table 6. The average for all samples, of 32.3 mg/kg, agrees closely with samples harvested at colour stage 5 and analysed at colour stage 9, in the first part of this project. It is also in line with results expected from fresh tomatoes from other literature.

There is considerable variation between replicates from the same sites. Although efforts were made to secure samples at the same colour stage, the variation in results suggests that uniformity of colour was not achieved, either from individual sites or between sites.

No effect of location on lycopene content could therefore be concluded from the results and consequently there was no identifiable influence of latitude.

The variation in results within replicates from an individual site also confirms the opportunity to influence lycopene content. Results also show that levels typical of currently marketed fruit are considerably less than the potential figures in more mature and riper fruit.

Table 6. Lycopene concentration in mg/kg of tomatoes cv Espero from 10 different locations.

Location	Lycopene content (mg/kg)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
Cleveland	16.5	29.6	23.7	23.3
IOW	25.7	27.3	29.4	27.5
Jersey	57.8	30.0	52.3	46.7
Kent	28.2	49.1	39.9	39.1
Lancashire	22.2	27.6	27.5	25.8
Somerset	35.1	43.8	29.3	36.1
Wales	23.3	30.4	19.5	24.4
Worcs	34.2	51.2	27.1	37.5
Yorkshire (1)	29.1	39.7	21.2	30.0
Yorkshire (2)	34.0	30.3	32.9	32.4
Average				**32.3**

Conclusions

a). Stage of ripeness

- The stage of ripeness, as described by the intensity of red pigmentation, is critical to the concentration of lycopene in tomato fruits of red cultivars. Fruit of both a classic and a cherry tomato cultivar showed an eight-fold increase in lycopene content between colour stages 1 and 9. If lycopene content of fruit is to be maximised, this factor needs to be addressed in any product specification.

- The lycopene concentration in fruits of both cultivars stored at ambient temperature for 7 days after reaching colour stage 9, increased further and by a factor of 50% or more. The effects of storage for periods longer than 7 days, or at lower temperatures than ambient, were not tested in this project and need to be so. Possible deleterious effects of longer storage, such as those on palatability and shelf life, need to be considered.

- Maximum lycopene concentrations were up to three times previously quoted figures for raw tomatoes. This gives the opportunity for promotion of this factor for fresh British tomatoes.

b). Cultivar and product type.

- There was a considerable variation in lycopene content between the cultivars tested.

- Some cultivars showed high lycopene levels. These included a speciality beefsteak variety, truss varieties such as Aranca, and the plum types Baby Sweetheart, Santa and Yolande. There is therefore the opportunity to influence lycopene content by cultivar selection and breeding programmes. Not surprisingly, non-red cultivars such as Golden Cherry, are low in lycopene.

- There is a difficulty in distinguishing the effects of cultivar from product type. Truss harvested types will tend to be more mature, on average, than loose picked classic types.

- Vineripe cultivars, such as Ferrari, are not only harvested at a more mature stage but often marketed at a more mature stage than standard types. Red Choice (“Campari”) had lower lycopene levels than expected in this project, but this may be because the sample was less ripe than requested.

- As with the comments under Stage of Ripeness above, more detailed and replicated assessments of the stage of ripeness at selection, followed by immediate analysis, would be necessary to distinguish effects of cultivar and product type.

- It is possible by cultivar selection and maturation of fruit, to market fresh tomato products with a much higher lycopene content than many currently exhibit. This is especially so with classic types marketed at the fairly immature stages commonly practised. Market research would be needed to elucidate potential price benefits for such products.

- The marketing of more mature fruit would need much more care in handling, to avoid damage. This would present particular problems with loose packed fruit. The use of long-life cultivars in this respect does not appear to be the answer to the problem. Fruit of two classic type cultivars imported from Spain and the Canary Islands had very low lycopene levels (approximately 17.0 mg/kg).

- The comparison with southern European fruit appears to offer promotional opportunities for British tomatoes. Because of the limited number of Spanish samples tested, more sampling will be necessary to confirm these results.

- If there is a market opportunity for high lycopene tomatoes, it may best be developed with truss harvested or vineripe types of fruit.

- There are high lycopene cultivars in current breeding programmes, such as those in Israel. Comparisons between such material and the potential levels in cultivars found in this project would be of interest.

- Analysis of processed tomato products showed high lycopene levels, as expected. In the case of tinned plum tomatoes this was little more than the highest fresh samples however.

- In relation to lycopene ingestion in the diet, fresh tomatoes may represent a greater intake relative to processed products than might be thought to be the case. This is due to the small servings of concentrated products used in cooking. More detailed information on typical dietary intakes is needed to clarify this comparison.

- Cherry and mini-plum cultivars such as Santa, are relatively high in lycopene when ripe and this may be of particular interest in promoting consumption by children, especially when coupled with the higher flavonoid concentration known to be in cherry tomatoes.

c). Location of production.

- No effect of production location on lycopene content of fruit can be concluded from this project, because of inconsistencies in results between individual replicates and difficulties in ensuring that all samples were selected and analysed at exactly the same colour stage. Any effect might, in any event, be obscured by differences in the production techniques used by different growers, irrespective of their location. However, the average lycopene content from the range of samples tested (32 mg/kg) agreed with figures quoted in the literature for fresh tomatoes.

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References

1. *R Doll and R Peto*
   The causes of cancer: quantitative estimates of avoidable risks of cancer in the United States today.
   J. Nat. Cancer Inst., 66: 1191-1308, (1981).

2. *H Gerster*
   The potential role of lycopene for human health.
   J.Amer.College Nutr., 16: 109-126, (1997).

3. *G Block, B Patterson and A Subar*
   Fruit, vegetables and cancer prevention: A review of the epidemiological evidence.
   Nutr. Cancer, 18:. 1-29, (1992).

4. *J H Tinkler, F Böhm, and T G Truscott.*
   ***Dietary carotenoids protect human cells from damage**.*
   J. Photochem. Photobiol., B: Biol., 26:, 283-285, (1994).

5. *Di Mascio, Kaiser and Sies*
   Arch. Biochem., Biophys., 274: 532, (1989).

6. *F Böhm, J H Tinkler and T G Truscott.*
   Carotenoids protect against cell membrane damage by the nitrogen dioxide radical.
   Nature Med., 1: 98-99, (1995).

7. *S Francheschi et. al.*
   Tomatoes and risk of digestive-track cancers.
   Int. J. Cancer 59: 181-184, (1994).

8. *E Giovannucci et. al.*
   Intake of carotenoids and retinol in relation to risk of prostate cancer.
   J. Nat. Cancer Inst., 87: 1767-1776, (1995).

9. *E Giovannucci*
   ***Tomatoes, Tomato-Based Products, Lycopene and Cancer: Review of the Epidemiologic Literature**.*
   J. Nat Cancer Inst., 91:317-331 (1999)

10. *L Kohlmeier et. al.*
    ***Lycopene and myocardial infarction risk in the EURAMIC study**.*
    Amer. J. Epidemiol., 146: 618-626, (1997).

11. *Ribaya-Mercado et. al.*
    J. Nutr., 125: 1854, (1995).

12. *B A Periquet et. al.*
    ***Micronutrient levels in HIV-infected children**.*
    AIDS, 9: 887-893, (1995).

13. *J A Mares-Perlman et. al.*
    ***Serum antioxidants and age-related macular degeneration in a population-based case-control study**.*
    Arch. Opthalmol., 113: 1518-1523, (1995).

14. *F Shaladi and P K Wanasundara.*
***Phenolic antioxidants**.*
Rev. Food Sci. Nutr., 32: 67 (1992).

15. *L W Wattenburg.*
Inhibition of carcinogenesis by minor nutrient constituents of the diet.
Proc. Nutr. Soc., 49: 173 (1990).

16. *L W Wattenburg*
Chemoprevention of cancer.
Cancer Res., 45: 1 (1985).

17. *A Crozier et. al.*
Quantitative analysis of the flavonoid content of commercial tomatoes, onions, lettuce and celery.
J Agric. Food Chem., 45: 590-595 (1997).

18. *G S Omenn et. al.*
***Effects of a combination of beta-carotene and vitamin A on lung cancer and cardiovascular disease**.*
N. Eng. J. Med., 334: 1150-1155, (1996).

19. *Rapola et. al.*
The Lancet, 349: 1715, (1997).

20. *F Böhm, R Edge, E J Land, D J McGarvey and T G Truscott*
***Carotenoids enhance vitamin E antioxidant efficiency**.*
J. Amer. Chem. Soc., 119:, 621-622, (1997).

21. *J S Bertram et. al.*
Diverse carotenoids protect against chemically induced neoplastic transformation.
Carcinogenesis, 12: 671-678, (1991).

22. *R Edge and T G Truscott.*
Pro-oxidant and antioxidant reaction mechanisms of carotene and radical interactions with vitamins E and C.
Nutrition, 13: 992-994, (1997).

23. *I Paetau et. al.*
Chronic ingestion of lycopene-rich tomato juice or lycopene supplements significantly increase plasma concentrations of lycopene and related tomato carotenoids.
USDA Agricultural Research Service TEKTRAN (1998)

24. *S Clinton.*
Nutr. Rev. 56: 35, (1998)

25. *W Stahl and H Sies*
Uptake of lycopene and its geometrical isomers is greater from heat-processed than from unprocessed tomato juice in humans.
J.Nut., 122: 2161-2166, (1992)

26. *A Abdulnabi et. al.*
Determination of antioxidant vitamins in tomatoes.
Food Chemistry, 60: 207-212, (1997).

27. L Auclair, J A Zee, A Karam and E Rochat
Valeur nutritive, qualité organoleptique et produtivité des tomates de serre en fonction de leur mode de production: biologique, conventionnel, hydroponique.
Sciences des Aliments, 15: 511-528, (1995).

Appendix 1

HDC LYCOPENE PROJECT PC 167

TREATMENTS - HARVEST AND ANALYSIS STAGES

REPLICATE 3

	SAMPLE COLLECTION AND DISPATCH				
Day	01	04	08	11	15
Date	03/10/99	06/10/99	10/10/99	13/10/99	17/10/99
Espero					
E1/1		H/D			
E1/5			H	D	
E1/9		H		D	
E1/9+7 days	H				D
E5/5		H/D			
E5/9			H	D	
E5/9+7 days		H			D
E9/9		H/D			
E9/9+7 days			H		D
Favorita					
F1/1		H/D			
F1/5			H	D	
F1/9		H		D	
F1/9+7 days	H				D
F5/5		H/D			
F5/9			H	D	
F5/9+7 days		H			D
F9/9		H/D			
F9/9+7 days			H		D
Number to dispatch		6		6	6

Key:

Variety/**H**arvest stage/**D**ispatch stage for analysis.

e.g. F/5/9 = Favorita / harvest colour stage 5 / dispatch for analysis colour stage 9.