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Assessment of the flavour of fresh uncooked onions by taste-panels and analysis of flavour precursors, pyruvate and sugars

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Abstract: Flavour in fresh onions is dominated by volatile sulphenic and thiosulphenic acids that are liberated once alk(en)yl cysteine sulphoxide (ACSO) flavour precursors are cleaved by the enzyme alliinase after tissue disruption. The levels of pyruvate and ACSOs in over 100 samples of onions marketed in the UK were measured, and compared with assessment by taste-panels. There was a linear relationship between the content of ACSOs and pyruvate. Measurements of pyruvate indicated that the marketing classification of some types of onion did not correspond to their pyruvate levels. A significant linear relationship was found between a sensory measure of strength and pyruvate over the range 1.2–9.3 μmol pyruvate g^{-1} fresh weight. In most cases, when a flavour classification of sweet, mild or strong was applied to a sample of onions based on pyruvate content, the taste-panels agreed with the categorization. The taste-panels were unable to identify a sweet flavour in onions, except at low levels of pyruvate. Taste-panels were able to define a likeability character (attractiveness of flavour) for onions, which correlated with the level of pyruvate. However, for some varieties, the flavour classification or likeability did not correspond to predictions based on pyruvate levels alone. Pyruvate measurements were seen as a suitable method for routine quality control once the characteristics of a variety of onion had been established, but initial evaluations should include well-designed taste-panel assessments.

Keywords: onions; flavour; taste-panels; flavour precursors; pyruvate; sugars; strength; marketing

INTRODUCTION

Onions (*Allium cepa* L) are a major source of flavouring in fresh and cooked food, and are the second most important horticultural crop after tomatoes. They are used, produced and traded worldwide.[1] Bulb onions vary in flavour from very mild to extremely pungent when tasted uncooked. Most of the fresh onions sold in the UK are classified as strong cooking onions, but there is a growing market for varieties with a milder flavour that can be enjoyed when uncooked. Around 50 000 tonnes of onions are imported annually into the UK, mainly from Spain and Chile, to be sold as mild onions, although the flavour classification is assigned on mainly historical assumptions.

The odourless flavour precursors in members of the genus *Allium* have been identified as *S*-alk(en)yl cysteine sulphoxides (ACSOs) of which three are found in onion, namely methyl-(MCSO), 1-propenyl- (PrenCSO) and propyl- (PCSO) cysteine sulphoxide, although MCSO and PrenCSO are the major constituents.[2] They are cleaved by the enzyme alliinase to yield pyruvate, ammonia and sulphur containing volatiles.[3] The initial volatiles (the sulphenic and thiosulphenic acids) contribute to the strength of flavour and undergo rapid chemical change to volatile disulphides, which cause the pungent after flavours.[4] In intact tissue the ACSOs are in the cytoplasm while alliinase is compartmentalised in the vacuole.[5] The pungency of onions is primarily due to the rapid production of the lachrymatory factor thiopropanal *S*-oxide whenever tissue is damaged from the rapid breakdown of PrenCSO by the enzyme alliinase followed by the action of lachrymatory-factor synthase,[6] which gives rise to the tear producing effect.

In order for onion flavour to be specified in contracts or indicated to customers, a consistent measurement system is required. Although taste-panels should provide the reference points for any measurement

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system, they are not satisfactory for routine testing because only a limited number of onion samples can be tested at a time before the palate becomes saturated. In addition, they are time-consuming and expensive to run. The rather severe flavour of onions is not easy for people to judge accurately and consistently, so biochemical measures would be of particular advantage as a means of quality control.

The onion volatiles that can be smelt and tasted are major contributors to the flavour but are difficult to measure since they undergo rapid chemical change and, although methods based on GC-MS and biosensors have been proposed,[4,7–9] they have rarely been used for routine measurements.[10] Schwimmer and Weston[11] developed an approach that measured the amount of pyruvate after hydrolysis of the ACSOs. Trials with small taste-panels indicated a good correlation between pyruvate levels and olfactory threshold concentration[12] and with perceived pungency[13,14] although in almost half of repeated tastings the taste-panels did not agree with their earlier verbal descriptions.[14] Apart from these three studies involving taste-panels, attention has focused on the measurement of pyruvate or other chemical flavour components. Variations of the method to estimate pyruvate have evolved to suit the needs of situations such as onion breeding[15,16] and marketing.[17,18] Measurement of the ACSOs present in the intact tissue is an alternative approach that may be less subject to variation in the ratio of pyruvate to lacrymatory factor produced when used to test the wide range of onions sold in the UK.[19]

Sweetness is another factor in onion flavour. Sugars form a major part of the soluble solids of the onion, but their presence cannot be detected in the raw full-flavoured or strong onion because of the over-riding effect of the sulphur-based flavour volatiles. The three major sugars, fructose, glucose and sucrose, in addition to several of the soluble complex carbohydrate fructans, contribute 65% or more to the dry weight. The latter probably do not make much of a contribution to taste but function as storage carbohydrates that may contribute to the level of soluble sugars during long term storage of the onion.[20] Strong onions do not taste sweet, presumably because of the overpowering perception of pungency. The Rijnsburger-type onions sold in the UK as cooking onions have 8–10% sugar by weight in the bulb, but could not be described as sweet. The full sweetness of onions can generally only be appreciated after cooking, which vaporizes the pungent sulphur volatiles and inhibits any further enzyme action. Sweetness in many vegetables is an attraction and a selling point, and some onion varieties are advertised as 'sweet' or 'mild' to indicate that they can be enjoyed fresh, rather than cooked. However, there are indications that the flavour of some of these onions is variable and can be strong.[14] Substantial inter-bulb variation has been reported when onions have been analysed for traits associated with flavour, such as pyruvate and sugar levels, even among clones.[17,21]

Measurement of the level of the flavour precursor compounds or one of their products (usually pyruvate) in onion bulbs is frequently taken to be equivalent to measurement of the flavour, or pungency, of onions.[11,17,22] Very few studies have been reported of the relationship between these measurements and the perception of onion flavour by consumers, particularly over the wide range of onion varieties for sale in the UK. The aim of this study was to establish the relationship between taste panel and biochemical assessment across the onion types of interest to the UK onion production and retail industry.

MATERIALS AND METHODS

Onions

FB Parrish, Rustler Produce, Moulton Bulb Co, Bedfordshire Growers, G's Fresh Vegetables and ELGRO supplied onion bulbs for analysis from commercial crops and imports. Samples were taken from commercial shipments without further selection. The onion varieties used in this study were chosen to represent the range of varieties on sale within the UK. These included commercial Rijnsburger selections, all described as 'English' or 'Rijnsburger onions' within this study, along with other named UK-grown varieties including Radar, Shakespeare, Buffalo and Senshyu. Imported onions from Chile ('OSO' and 'Chilean' varieties), New Zealand, the USA ('Vidalia'), Spain ('Spanish') and Australia ('Tasmanian') were also analysed, referred to in this study by the names assigned by the importers. Bulbs of the English variety Kelsae (maintained at HRI) and of two breeding lines were also used in this study. One breeding line was of Spanish-style onions and the other a landrace (LR) used to derive a sweet onion for UK production. These onions were grown in small-scale field plots using conventional horticultural practices.

Pyruvate analysis

The pyruvate level of each batch of onions was estimated as the mean from analysis of five individual bulbs.[17] The amount of pyruvate produced by the hydrolysis of the ACSOs was obtained by subtracting a measurement of endogenous pyruvate, obtained from tissue where alliinase had been inactivated, from the total pyruvate generated after disruption of the tissue.

A 20 g section of the equatorial slice of the onion bulb was blended with 30 ml H_2O for 30 s (Kenwood, CH100 Mini Chopper). To estimate endogenous pyruvate levels, the slice was immersed in 30 ml pre-chilled 5% trichloroacetic acid and incubated at 4 °C for 1 h prior to blending. The resulting homogenate was transferred into a container and left to sit for 1 h at room temperature. An aliquot was then centrifuged for 4 min at 19 000 × g, and the supernatant diluted 1:20 in water for analysis.

The pyruvate concentration was measured by adding 1 ml of the aliquot to 1 ml H_2O and 1 ml 0.0125% 2,4 dinitrophenylhydrazine. The solutions were incubated at 37 °C for 10 min then the reaction was stopped with addition of 5 ml 0.6 M NaOH. The absorbance was read on a spectrophotometer at 420 nm and the concentration determined by reference to freshly prepared sodium pyruvate standards.[11]

Measurement of ACSOs by HPLC analysis

The method for ACSO extraction was modified from Edwards *et al*.[19] Five onion bulbs were sampled from each batch to be tested, removing a 2 g portion of an equatorial slice from each. The pooled tissue was frozen in liquid nitrogen for at least 5 min, then added to 100 ml of pre-chilled extractant (methanol:chloroform:water (12:5:3) containing 10 mM hydroxylamine) and incubated overnight at −20 °C. Then 10 ml was transferred to a centrifuge tube and 5.5 ml H_2O and 4.5 ml chloroform were added. After mixing, the phases were separated by brief centrifugation and the upper phase was collected for purification by ion exchange chromatography. A column (2 ml bed volume) of Amberlite IR120 ion exchange resin (Sigma) was converted to the H^+ form by washing with 5% v/v HCl (flow rate approximately 0.25 ml min^{-1}). The column was washed with 10 ml H_2O (flow rate 1 ml min^{-1}) then the upper phase of the extract was applied to the column (flow rate 0.1 ml min^{-1}). The column was rinsed with 10 ml H_2O (flow rate 1 ml min^{-1}) and the ACSOs were finally eluted with 7 ml 2 M NH_4OH (flow rate 0.25 ml min^{-1}) and freeze-dried.

This extract was resuspended in 1 ml 0.03 M HCl, dispersed by sonication and filtered through a 0.45 µm filter (Whatman, Brentford, Middlesex, UK) ready for HPLC analysis. The ACSO analysis used isocratic conditions described by Edwards *et al*[19] in a Gilson (Anachem) HPLC system (234 autoinjector, 307 pump and 118 UV/vis detector). The injection volume was 50 µl and separation occurred on two Spherisorb S3 ODS2 columns (each 4.6 × 15 cm, Phase-Sep, Deeside, UK) in series at room temperature preceded by a guard column. The mobile phase was 0.03 M HCl, degassed by sonication, at a flow rate of 0.9 ml min^{-1}. The ACSOs were detected at 215 nm.

Soluble solids content determination

The aqueous extract from onions prepared for the measurement of pyruvate was also used to obtain a routine measurement of sugar levels using a refractometer (Bellingham and Stanley Ltd, Tunbridge Wells, Kent, UK), with sugar content expressed as percentage sucrose equivalents.

Taste-panel assessment

Four taste-panels were assembled from among the directors and staff of four onion supply companies in the UK. The panels, usually seven members, were therefore composed entirely of people of working age and were approximately balanced for gender. Panel members attended a one-day training session during the early part of the project. They sat monthly over 2 years and followed a protocol that was developed after experience in preliminary tasting sessions for all three series of tasting sessions reported here.

The onions, labelled to hide their identity, were distributed to the taste-panels and the biochemical analysis laboratory by an independent organization that also collected and collated the results. The taste-panels operated at their place of work with the samples for each taste trial being prepared out of sight of the tasters by an individual who was not a taster so that the appearance of the onions could not give rise to expectations of its flavour. All panellists recorded their views on purpose-designed forms, which were returned to one central office for analysis. It was inevitable that each panel did not always have the same members. However, the external supervision of the taste trials, the agreed protocol and the interest of the people involved in producing useful results produced data-sets that could be analysed meaningfully.

The first series of taste-panels

This series of nine sessions tasted a wide range of onions sold in the UK. Samples of these onions were analysed for both pyruvate and ACSOs with the aim of determining the suitability of each method for reporting the flavour of a wide range of onion types. On each occasion, the taste panellists assessed four varieties of onions. The taste trials were designed so that the four taste-panels each tasted each of the four onion varieties. It was therefore possible to set a different order of tasting for each panel to ensure that each variety was tasted once in each of the four possible positions in the tasting sequence. The aim of this was to minimize bias introduced by the residual effect on taste perception of the previously tasted onion. For the test varieties, each panellist tasted a separate onion so that variability between tasters would be confounded with variability between onions but the average over all 28 panellists would give a better measure of the variety.

For the first three sessions, tasting a piece of a single relatively mild 'Vidalia' onion preceded tasting of the four test varieties. The test varieties were the same in all three sessions and were chosen to represent the range of types available in the UK including the relatively mild and watery English Kelsae, a UK grown 'Spanish' type onion and UK grown Rijnsburger. For the remaining six sessions the 'Vidalia' standard was not used partly because they were only seasonally available and partly because it was felt that five samples was too many for the panels to taste at one time. The onions in these six sessions consisted of further examples from within the same range of types as the first three sessions.

The panellists were asked to assess six qualities of each sample, scored on a categorical 1–7 scale, with 1 being the least strong response in each case. They were provided with written descriptors for guidance in their assessment. They were asked to give three measures of pungency, namely initial pungency, bitterness and aftertaste, where low values indicated a low level of that attribute. These three were chosen because they tended to appear to the panellists to be separate independent characteristics, any of which might be exhibited by an onion. The panellists were also asked to give scores for use, sweetness and texture. The use score gave a view on the suitability of the onion for salads, cooking or both, and could be considered to be a further measure of pungency. Low values on the sweetness score indicated low sweetness. For the texture scores, low values indicated crisp and juicy and high values indicated tough and dry. For statistical analysis of the results the ordinal values associated with each option were used.

The second series of taste-panels—assessment of onions by classification

The objective of this series of trials was to investigate whether the panellists agreed with classes that had been assigned to onions based on pyruvate analysis. Onions with a pyruvate level below 4.0 μmol g^{-1} fresh weight were classified as sweet, those with a level between 4.0 and 7.0 μmol g^{-1} fresh weight as mild, and onions with levels above 7.0 μmol g^{-1} fresh weight were described as strong.

A wide range of UK produced and imported onions were assessed in a total of eight tasting sessions at approximately monthly intervals. The onions were assigned codes to conceal their identity during both pyruvate analysis and taste-panel assessment. A classification was assigned based on the pyruvate analysis and this was followed by taste-panel assessment. The panels tasted three varieties of onions on each occasion, every taster tasting a different bulb of each variety. The panellists were told the descriptor for the first variety that they tasted in each session and were asked to agree or disagree with that classification. Although the tasters were not given information about the second and third varieties, the bulbs were presented in order of increasing pyruvate value to minimize the effects of tasting a bulb after a more strongly flavoured one. The panelists were asked to classify the latter two bulbs that they tasted into the category they thought most suitable. These results were compared with the results from pyruvate analysis.

The third series of taste-panels—the flavour of 'sweet' onions

This series of trials investigated the perception of flavour in onions that are marketed as 'sweet' and become available during summer in the UK. The onions were scored for three criteria: sweetness, use and description. Sweetness was scored on a 1–5 scale where 1 represented a bland lack of sweetness, 3 was just acceptable for an onion to be termed 'sweet' and 5 was very sweet. The panellists were asked to assess use on the basis of whether the onion would be best used uncooked in salads or would be better cooked. For statistical analysis this was scored as 1 for uncooked and 2 for cooked. The panellists were also asked to give a Description as potential consumers, indicating whether they felt that the onion should be described for sale as 'sweet'. For analysis, agreement that it should be sold as sweet was given the value 1 and disagreement was given the value 0. The pyruvate level of these onions was also analysed, along with their sugar content.

Statistical analysis

Data from the taste-panels and biochemical measurements were analysed using GenStat 5 for Windows (VSN International Ltd) in the version current at the times of analysis.

RESULTS

Assessment of pyruvate levels in UK home-grown and imported onions

The pyruvate level of over 100 samples of onions was measured, encompassing the range of onion types sold in the UK. The majority of samples came from commercial shipments entering UK supermarkets and onion processing. Thus the mean pyruvate levels shown in Fig 1, where data obtained from multiple samples of each type of onion have been pooled, represent the typical experience of consumers during the year. The survey indicated that the traditional marketing categories of onions do not always have the pyruvate levels that their category seems to imply.

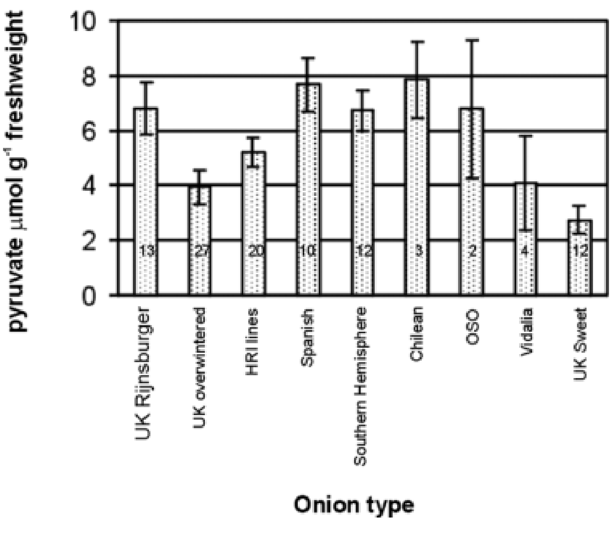

Figure 1. Survey of pyruvate levels in UK homegrown and imported onions. Error bars show 95% confidence intervals for the type means. Figures on bars are the number of samples of each type that were assayed. Key to onion types: UK Rijnsburger = UK grown Rijnsburger-type onions; UK overwintered = UK-grown over-wintered varieties (eg Buffalo, Radar); HRI lines = genotypes from Spanish-type lines at HRI Wellesbourne; Spanish = Spanish-grown 'Spanish Mild' type onions; Southern Hemisphere = imported onions from Australia, New Zealand; Chilean = imported onions from Chile; OSO = imported Chilean 'Oh So Sweet'-type onions; Vidalia = imported USA 'Vidalia' type onions; UK Sweet = derived from landrace LR.

Although the pyruvate level of UK grown Rijnsburger-type onions is in the range 5.8–7.7 μmol g^{-1} fresh weight, several other types of onions have similar high levels. These include Spanish and Chilean onions, which are usually marketed as 'mild'. In contrast, Vidalia and UK Sweet onions, marketed as 'sweet', had a lower pyruvate content, with mean levels below 4.0 μmol g^{-1} fresh weight. Interestingly, UK over-wintered onions, marketed as 'strong cooking' onions consistently contained low levels of pyruvate, in the range 3.5–4.6 μmol g^{-1} fresh weight.

Relationship between pyruvate levels and taste-panel assessment

Preliminary taste sessions indicated that untrained and inexperienced panellists were not very successful at recording their perceptions of onion flavour. It was also apparent that the sequence in which the onions were tasted might influence the results, so that a highly flavoured onion tasted before a milder one would make the second seem more pungent than if the order of tasting had been reversed. As a consequence, a protocol for tasting sessions, including initial training for panellists, was developed and used in all the results reported here.

We investigated how four measures recorded by the taste-panels were related to pungency, namely initial pungency, bitterness, aftertaste and use. It became clear, as the taste panel data accumulated, that the best relationship with the biochemical tests was obtained by using the sum of all four of the pungency-related scores. This was demonstrated using principle components analysis of the correlation coefficient matrix for these four taste-panel measures which found 89% of the information in the first principle component with approximately equal loadings for the measures. The remaining 11% of the variation was partitioned in a further three principle components that were not significantly different in magnitude and could be considered to represent noise. There was no evidence of any interaction between onion varieties and individual measures. Repeating these analyses after the accumulation of further taste-panel data gave similar results. There being no clear reason to give any bias to any of the four scores, it was decided that they should be simply summed to give a value that will be referred to as 'strength'.

The relationship between strength and pyruvate measurements in the first three taste-panel sessions is shown in Fig 2 ($R^2 = 0.9029$, $p < 0.0001$). Further testing of a wider range of varieties in six more sessions produced a greater dispersion of points (Fig 3). Regression analysis showed that the variability was largely due to session effects with no evidence to suggest that the slope of the line varied between sessions (Table 1). It was the view of the taste panelists themselves that they had some difficulty fixing a baseline for their scores but that they were reasonably confident of their relative scoring within a session.

Subtracting the session effects from the data and fitting a least squares regression line gives the data points and the full line shown in Fig 3. When the data analysis is repeated for only the first three, or last six, tasting sessions (Fig 3; dashed, dotted lines) there is no significant difference between the fitted lines.

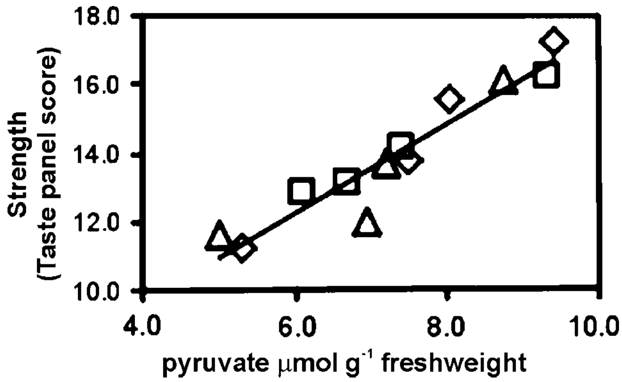

Figure 2. The relationship between onion flavour strength and pyruvate levels from the first three taste-panel sessions in the first series. Session 1 = ◊; session 2 = □; session 3 = △.

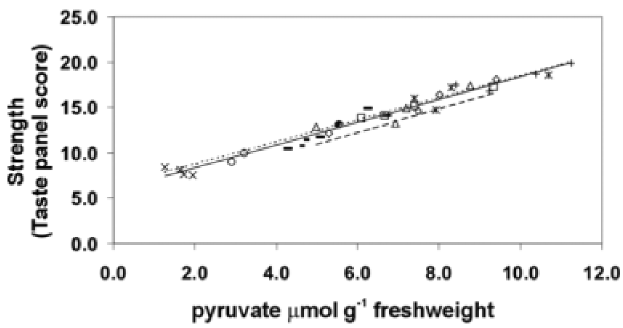

Figure 3. The relationship between onion flavour strength and pyruvate levels in all sessions of the first series of taste-panels. Solid line = regression line fitted by least squares method to data points from all nine tasting sessions. Dashed line = regression line fitted by least squares method to data points from first three tasting sessions only. Dotted line = regression line fitted by least squares method to data points from last six tasting sessions only.

Table 1. Regression analysis of all nine taste-panel sessions in the first series of trials

Added term	Percentage variance accounted for by the added term	Variance ratio for the variance accounted for by the added term	Degrees of freedom for the added term	*F* probability
Constant + pyruvate	17.5	7.37	1	0.011
+ session	62.6	14.07	7	<0.001
+ pyruvate × session	0.0	1.00	7	0.469

The full line is fitted to the points shown, which have been adjusted by the session effect estimates from an analysis of all nine sessions. The dotted line is obtained by the same procedure as the full line but omitting the first three sessions (points not shown). The dashed line is fitted to the unadjusted points from the first three sessions (points not shown).

Relationship between alkyl cysteine sulfoxide measurement and pyruvate levels

Many of the onions that were tasted in these taste-panel sessions were assayed for ACSOs as well as for pyruvate. Total ACSO levels were highly correlated with pyruvate levels (Fig 4; $R^2 = 0.864, p < 0.0001$). No reason was found for regarding ACSO measurements as superior to pyruvate measurements in the assessment of onion pungency.

Relationship of taste-panel perception of sweetness to sugar and pyruvate levels

Fig 5 shows that there was a significant inverse relationship between the pyruvate level of onions and their sweetness, as perceived by the first series of taste-panels ($R^2 = 0.4397, p < 0.05$). High onion strength, as indicated by the correlated measure of pyruvate, is associated with low levels of perceived sweetness, and vice versa. Some onions with mid-range pyruvate are also perceived as sweet. It may be that this latter effect is due to a delay in the perception of the flavour volatiles, resulting in initial sweetness followed by a pungent flavour. This effect was frequently noted

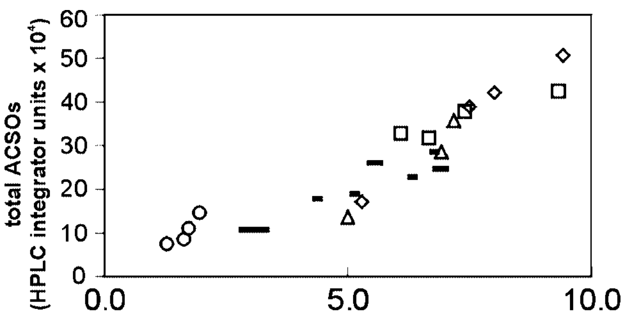

Figure 4. The relationship between ACSO and pyruvate levels in onions from the first series of taste-panels. Each type of symbol indicates the results from one set of taste-panels.

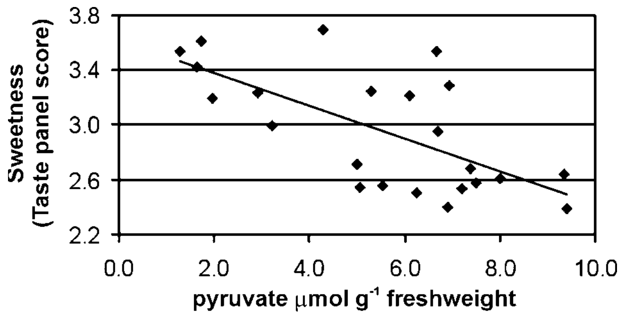

Figure 5. The relationship between sweetness (taste-panel scores) and pyruvate levels (μmol g^{-1} fresh weight) in the onions.

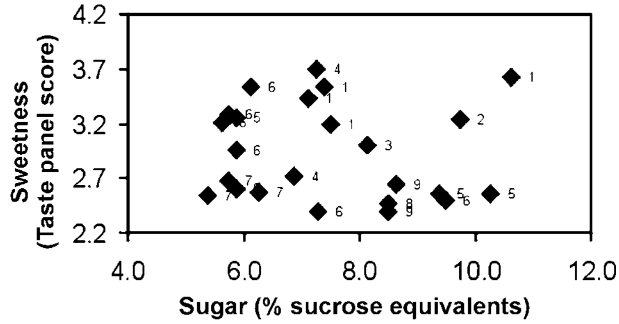

Figure 6. The relationship between sweetness and the amount of sugar (expressed as equivalent percentage sucrose). Numbers adjacent to the points are pyruvate (μmol g^{-1} fresh weight) rounded down to the nearest integer.

by the taste panellists. There was no relationship between sugar levels (measured by refractometry) and perceived sweetness (Fig 6; $R^2 = 0.0088, p < 0.662$). There was also no relationship with sweetness when levels of individual sugars (glucose, sucrose, fructose) were measured by HPLC (data not shown). The indication is that, as illustrated in Fig 6, all the onions tasted here contained sufficient sugar to be perceived as sweet, and therefore other factors determined the perception of sweetness. It is clear that pungency was masking perception of sweetness once the pyruvate level exceeded about 4.0 μmol g^{-1} fresh weight.

The ability of taste-panels to categorise the flavour of onions

The results from the first series of taste-panels indicated a good relationship between perceptions of onion strength and levels of pyruvate. However, there is commercial interest in whether pyruvate level can be used as a basis for classifying onions. The taste panellists were therefore asked whether they agreed with a classification that had been assigned on the basis of pyruvate content, and whether they could classify two further onion samples. The results of eight trials are shown in Table 2.

It is notable from the first eight rows of Table 2 that, when presented with pre-classified onions and asked to agree or disagree, the panels showed high levels of unanimity. They generally agreed with the pre-classification of the onions presented to them in six out of eight sessions, but clearly did not accept the classification on two occasions.

The 16 cases when the panels were asked to classify the onions they had tasted also showed general agreement with the classification assigned from the pyruvate level (last 16 rows, Table 2). Agreement is, however, much less clear-cut than with the pre-classified onions. This is particularly obvious near category borderlines, as exemplified by one type of New Zealand onion, which with a pyruvate content of 6.74 μmol g^{-1} fresh wt was very close to the mild/strong borderline (set at 7.0 μmol g^{-1} fresh wt). The panellists were divided 0.41:0.59 on whether it should be in the mild or strong category (see Table 2). Summed over

Table 2. Results of the second series of taste-panels. Onions were categorized sweet/mild/strong based on pyruvate content. Taste panellists were asked to agree/disagree with the category that had been assigned (upper eight onion types in table) or to assign the onions to the category sweet/mild/strong (lower 16 onion types). Values shown are proportion of panellists assigning onions to each category

Type	Pyruvate (μmol g^{-1} fresh wt)	Category	Agree	Disagree	Sweet	Mild	Strong
OSO	6.22	Mild	0.93	0.07			
English	6.25	Mild	0.81	0.19			
Vidalia	4.44	Mild	0.88	0.12			
Vidalia	5.63	Mild	0.97	0.03			
LR	2.09	Sweet	0.975	0.025			
LR	2.24	Sweet	0.74	0.26			
Red Tasmanian[a]	3.34	Sweet	0.225	0.775			
Tasmanian[a]	6.45	Mild	0.3	0.7			
Chilean	7.21	Strong			0.04	0.5	0.46
Spanish	8.48	Strong			0.07	0.21	0.72
New Zealand	7.15	Strong			0	0.31	0.69
Chilean	7.67	Strong			0.04	0.27	0.69
New Zealand	6.74	Mild			0	0.41	0.59
English	7.85	Strong			0.04	0.41	0.55
English	5.11	Mild			0.06	0.62	0.32
Chilean	8.67	Strong			0.03	0.38	0.59
Tasmanian[a]	5.75	Mild			0	0.03	0.97
New Zealand	7.23	Strong			0	0.15	0.85
Red Italian	4.19	Mild			0.35	0.45	0.2
Red New Zealand	10.62	Strong			0.2	0.33	0.48
Radar	2.31	Sweet			0.425	0.5	0.08
Shakespeare[a]	2.51	Sweet			0.3	0.63	0.08
Senshyu	4.25	Mild			0.06	0.57	0.37
Shakespeare	4.99	Mild			0.2	0.485	0.32

[a] Disagreement between categories assigned by panellists and from pyruvate levels.

all the sessions in this series, 301 onions were placed in the same category as the pyruvate results by their human tasters, with disagreement on 227 occasions. The probability of getting equal or greater agreement than this with random choices being made is <0.001, so it is very unlikely that the apparent agreement is due to chance alone.

Of particular note in these results are the four marked by an asterisk that clearly do not fit the pattern of the others. In these, the taste panellists strongly disagreed with the classification assigned on the basis of pyruvate levels, assigning the onions to a category with higher pyruvate content. It is not known why this happened, but the fact that it involved three of the six varieties of antipodean origin may not be coincidence. For a fourth sample of antipodean onions, Red New Zealand, despite the pyruvate content being the highest in the survey, the taste panellists did not confidently assign it to the strong category.

Taste-panel perceptions of the overall likeability of onions

Analysis of the pungency-related scores had shown that they could be combined into a single informative value, strength. Investigation of the measures used by the panellists to assess the flavour of onions that were marketed as 'sweet' indicated that another single characteristic could be derived to represent their perceptions. The taste-panel scores for sweetness and description were found to be closely correlated ($R^2 = 0.757$, $p < 0.001$). The data have, therefore, been treated in a very similar way to the derivation of strength to give another single characteristic, defined as a likeability score. This score was constructed by dividing the sweetness score by 5, to give it the same weight as the description score, and adding the result to the description score to give a range of values between 0 and 2, where 2 indicates the onions with the most acceptable flavour.

Figure 7 shows the result of plotting likeability against pyruvate. The majority of the points (diamonds) appear to indicate an inverse linear relationship between likeability and pyruvate levels. After fitting a regression line, the dotted lines indicate the band encompassing two standard deviations either side of the line, which should be expected to contain 95% of the points if those points are just randomly deviating from the assumed linear relationship. Onions with a lower pyruvate content, particularly below $5.0\,\mu$mol g^{-1} fresh weight, were rated as more likeable by the taste-panels.

The marketing of some of these varieties focuses on their sweetness (eg Vidalia and OSO). Four onion samples were more than two standard deviations from the regression line, indicating that the taste-panels found them particularly likeable, even though, in the case of the OSO sample, the pyruvate content was rather high. This suggests that factors other than

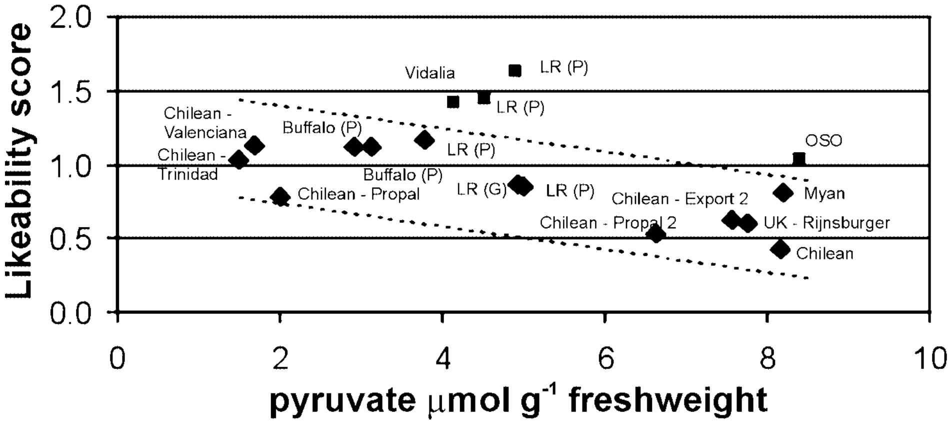

Figure 7. Assessment of the likeability of onions including some marketed as 'sweet'. Landrace (LR) and Buffalo were grown in the UK in 1999–2000 at two sites (P and G). The other labels are taken from the bags of onions as supplied.

the level of pyruvate affect human judgement of the likeability of onions.

DISCUSSION AND CONCLUSIONS

It is apparent from our survey of 103 samples that the categories applied in the UK to onions for marketing purposes do not necessarily correspond to those that would be applied by an objective measure such as pyruvate level (Fig 1). Spanish and Chilean onions that have been marketed as 'mild' for many years contain higher average levels of pyruvate than the strong Rijnsberger cooking onion. This discrepancy makes it important to investigate the relationship between human perceptions of onion flavour and pyruvate levels before adoption of pyruvate as a standard in commercial contracts or in information to consumers. Although there has been considerable discussion about the application of pyruvate analysis to the assessment of onions[15,18,23] few studies have included taste-panels.[12–14] The most extensive published survey is of nine onion varieties tasted by a panel of three people,[14] where repeated tastings of five varieties showed agreement with the panellists earlier verbal description on only three occasions. In contrast, the results of our study indicate that, once set up in an appropriate manner, taste-panels give reliable and reproducible results. They show that measurements of the level of pyruvate in onions can indeed generally stand as a proxy for the more complex concept of onion flavour. Extensive taste panelling has shown a statistically robust relationship between perceived strength and pyruvate levels over the full range of strengths available (Fig 3). We have also demonstrated an inverse relationship between sweetness and pyruvate levels (Fig 5), where the sweet flavour from the sugars present in all onions is only apparent to taste panellists at lower levels of pyruvate where it is not masked by the strong flavour volatiles. It is therefore evident that human perceptions can distinguish between onions of different pyruvate content, at least in controlled taste trials.

The taste-panel protocol initially used a low pungency onion as a reference standard. The results suggest that this may have assisted the panels in fixing the position of the scale for their scoring. Provision of a reference in all tasting sessions was not possible because of the seasonal availability of suitably mild onions in the UK. Also, with experience, all involved tended to agree that four was the maximum number of onions that the panels should be asked to assess in one session, in agreement with an earlier study.[14] While the problem was resolved statistically to our satisfaction, there is a clear suggestion that a taste standard should be sought for future taste-panels.

The results of the taste-panels at classifying onions suggests that the relationship of pyruvate levels to onion classification is complex. The successful marketing in the UK of onions with a high level of pyruvate as 'mild' also suggests that factors other than pyruvate are involved in consumer acceptance. Appearance and packaging might be a factor for consumers since 'mild' onions are large, an attractive brown colour with good skin finish and are frequently sold in convenient linear packs of three, contrasting with the smaller 'cooking' onions of more variable appearance that are generally sold loose. The taste-panels did not have these visual cues and, although they were successful in placing onions into sweet, mild or strong classifications most of the time (Table 2), there were interesting exceptions. For example, the taste-panels thought that all the Tasmanian onions were much stronger flavoured than their pyruvate content indicated. Among the 'sweet' onions, some varieties were more likeable than was predicted by their pyruvate content (Fig 7). Human perceptions of onion flavour may therefore be influenced by non-visual factors other than pyruvate. Obvious candidates include the texture and water content of the onion, where crispness is more appealing than a watery or tough texture. The flavour volatiles may also be involved. We have shown a good correlation between total ACSOs and pyruvate (Fig 4). The dominant flavour volatile is propanthial *S*-oxide, derived from prenCSO after the successive action of alliinase and lachrymatory factor synthase.[6] Onion cultivars are known to vary in balance between the ACSOs due to both genetic and environmental factors[22–24] and it is possible that there may also be variation in the lytic enzymes between cultivars that could affect the levels and rates of formation of the flavour volatiles. Differences in volatiles have been detected between *A cepa* onions and shallots,[9] and a complex relationship between prenCSO and propanthial *S*-oxide has been demonstrated for two onion cultivars.[10] These possibilities could be addressed through a survey of flavour volatiles, physical characteristics and taste-panel perceptions in a wide range of onion cultivars.

The strong and lingering nature of the flavour of onions makes the application of biochemical tests to its assessment appealing. Pyruvate, ACSOs and propanthial *S*-oxide have all been suggested as routine measures of the sulphur-derived flavour compounds.[10,18,19] The comparative simplicity of measurements of pyruvate, and the possibility of automation[25] make it currently the most popular candidate. The good linear relationship in our comparison of the yields of pyruvate and ACSOs from a very wide range of onions (Fig 4) supports the use of pyruvate. However, it was clear from the taste-panel responses to the classification of onions that pyruvate levels were not a good guide to the flavour of all varieties. Taste-panels can strongly disagree with a classification of some onions based solely on pyruvate content and can rate varieties as more likeable than is predicted by pyruvate measurements. For onions where flavour classification or likeability has been validated by a taste-panel, pyruvate may be suitable for routine monitoring of quality. However, taste-panels have an important place in establishing the consumer acceptability of new onion varieties.

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