Final Report for HDC

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Validation of Mushroom Bruisometer (M 19a)

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PRACTICAL SECTION FOR GROWERS

Background

Quality is one of the major factors affecting the competitiveness of the British mushroom industry. Mushroom colour is a chief determinant of quality. Mushrooms are normally white but can discolour as a result of (a) natural ageing (senescence) or (b) mechanical damage leading to bruising. It is known both to growers and scientists by observation and experience, that mushroom bruisability can vary from crop to crop and even within a crop. This variability of bruising can be observed when comparing crops of the same strain. Differences in bruising are not therefore due to genetic differences but to how the mushrooms are grown (agronomy and environment). It is highly likely that, if the agronomic and environmental factors which influence bruising can be identified, then quality improvements will follow. However, up to recently there has not been a device which can inflict controlled bruising treatment onto mushrooms and so research into which factors affect bruisability can not take place. HDC Project M 19 examined the cellular basis of texture. One of the conclusions of the project was that most mushroom bruising occurs as a result of a mechanical treatment known as 'slip-shear' i.e. downwards force and sideways movement. As a result HRI staff have been collaborating with the Mechanical Engineering Department of Coventry University to design and build two prototype bruisometers, devices which can inflict a controlled and repeatable ship-shear force onto mushrooms. The bruisometers were handed over to HRI in the spring of 1998 and demonstrated to the HDC Mushroom Panel.

Summary of results

The aims of this HDC Project (M 19a) are to validate the bruisometers (assess whether they work) and to identify how they might be improved.

(1) Firstly, the two bruisometers were compared for ease of use and one of them was chosen as the best design and used for all subsequent operations. The information on the use and operation of the bruisometers was passed on to Coventry University to guide the design of the second generation of bruisometers.

(2) The validation question was determined by whether the bruisometer could distinguish between 'bruise-resistant' or 'bruise-susceptible' mushrooms. As a result of the innovatory nature of this work, we do not know how to grow mushrooms of different bruisabilities ('bruise-resistant' or bruise-susceptible'). We used crop age, flush number, strain and humidity as a means of producing a range of different mushrooms and the bruisometer was able to distinguish bruisability between them. It is therefore validated.

(3) The next question was to examine how bruise colour might be affected by how the bruisometer is used (weight of bruise, number of slip-shear treatments (passes) and the duration of time between bruising and observation of colour). The colour of the bruise area became more intense with increasing weight of bruising treatment and number of bruising passes. Also the longer one waited (up to 4 hours) after bruising, the more intense the bruise colour became. However, the practical considerations for the potential commercial use of the bruisometer is that farms would want a result within an hour or two. Also the bruise colour must be similar to that found during retail sale. A more intense colour would be meaningless and may be too strong to distinguish between different bruisabilities, and a too mild bruising treatment would result in weak

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colour and again unable to distinguish different bruisabilities. From these considerations and experiments, a set of specifications/conditions was chosen to be incorporated into the design of the second generation of bruisometers (in collaboration with Coventry University).

(4) The final part of the project examined the bruisability of calcium chloride treated mushrooms (from an experiment of HDC Project M 37). The calcium chloride treated mushrooms had a significantly less intense bruise colour than the water treated mushrooms. This is further validation of the bruisometer.

Action points for growers

The bruisometer is only a prototype and is not available to growers at present. Following discussion at the HDC Mushroom Panel it was agreed that the bruisometer should be used to investigate agronomic factors affecting bruisability of the mushroom. Proposals for further work are currently under discussion.

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SCIENCE SECTION

Introduction

Quality is one of the main factors determining the competitiveness of the British mushroom industry. Mushrooms lose quality as a result of either 'senescence' (the process of natural deterioration in the hours and days after harvest), or mechanical damage (which leads to discolouration and bruising and can occur in seconds). HDC Project M19 demonstrated that the mechanical process most damaging to mushrooms (in terms of bruising) is the process of 'slip-shear'. An example of slip-shear is when a finger slides over the surface of a mushroom with some downwards force. This occurs during picking and to a lesser extent when mushrooms rub against each other before or after harvest.

Bruising or mechanically-induced discolouration is one of the major causes of quality-loss for mushrooms, but bruisability can vary from crop to crop indicating that the differences in bruisability are due to differences in growing environment and agronomy. It has not been possible, in the past, to study which environmental or agronomic factors encourage bruising as there has not been a means to deliver a repeatable bruising treatment. The only reports that the authors are aware of to examine the effects of bruising are those of Noble, Burton and Atkey (1992) and Burton and Noble (1993). These authors delivered the mechanical damage by a shaking box but thought the treatment was too harsh to discriminate subtleties. This technique has recently been copied by Kukura (1998, a and b) to examine the effect of calcium chloride on bruising.

Recently, Kerry Burton and Tanouja Rama of HRI have been collaborating with the Mechanical Engineering Department of Coventry University in the design and building of two devices to inflict a controlled amount of slip-shear force onto the surface of mushrooms (Rama and Burton, 1998). Two design teams, each of four people, have been working on production of two such devices, which we are calling 'bruisometers'. Both bruisometers have been released to HRI in June 1998. The bruisometers are of different designs. These bruisometers should be viewed as prototypes.

The use of these machines has potential for growers for quality control and feed-back for effect of strains/materials/agronomy on quality and for researchers in determining the main environmental and agronomic factors to influence bruisability. Before these stages can be reached, the prototype has to be validated (to find if it can differentiate between mushrooms of different bruisability) and its specifications for use determined.

As there has not previously been any device to inflict a controlled amount of slip-shear force onto the surface of mushrooms, there is little information of which agronomic/environmental factors result in bruise-resistant or bruise-susceptible mushrooms. An important aspect of validating the bruisometer is to demonstrate whether it can distinguish between mushrooms of different bruisabilities. Initially mushroom bruisability was determined during crop age as it is known that bruisability can vary with flush number. Also different mushroom strains, growing room humidities and calcium chloride concentrations (in the irrigation water) were used to create possible differences in bruisability. This exercise is not an attempt to firmly establish which agronomies/environments can influence bruisability but only to use different bruisabilities to test and validate the bruisometer.

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Materials and Methods

The Mushrooms Used

The mushrooms used for this project were grown at either HRI-Wellesbourne or the Monaghan-Middlebrook farm in Avon. Unless otherwise stated they are of strain A 15. Bruise-free, clean white mushrooms were chosen and very carefully harvested taking care not to bruise the caps by finger contact.

Choice of Bruisometer

Two prototype bruisometers had been designed and built by Coventry University. The two designs are different even though they both contain features which are in principle similar:- (a) the application of variable force, (b) a means of holding the mushroom, and (c) a way of moving the mushroom relative to applied force. Both bruisometers are portable and electrically operated using batteries.

Bruisometer One

This device (see Photograph 1) applies a variable force using a constant force spring attached to a pivoted bar which is in contact with the mushroom via a test-head. The force can be varied by changing the position of the spring along the bar onto notched locations. The lowest available force is 0.396 Newtons (N). There are 15 increments of 0.196 N to a maximum force of 3.34 N.

The mushroom is held cap downwards in the device by a triangular arrangement of spikes. The mushroom can then be moved to the contact patch using a rack and pinion operated by a thumb-wheel via a gearbox.

The slip-shear treatment is delivered by rotating the mushroom while the constant force spring is applying force radial to the mushroom via the test-head. The rotation was driven by a battery-operated electric motor geared to a maximum of a complete rotation in one second. Different speeds are achieved using three alternative sets of resistors which can be switched to apply different voltages to the motor. The weight of this device is approximately 1 kg and dimensions are 220 x 150 x 64 mm.

Bruisometer Two

The variable force for this device (see Photograph 2) can be applied using 13 block masses each of 15g. These block masses are located on vertical guides. They could be pinned away from the test-head or positioned on the test-head. The mass variation on the test-head ranged from 15g (minimum) (0.147 N) and could be increased by 15g increments (0.147 N) to a maximum of 195g (1.92 N).

The block masses can be lowered onto the mushroom which is held on a triangular arrangement of spikes on a pivot-bed. The slip-shear treatment is delivered by the weight of the block masses while the mushroom pivots over a range of 50°. The pivot-bed is operated by a battery-driven motor and gear set. This device was fitted with a control circuit to operate

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the speed and direction of the pivoting action. The weight of this device is approximately 2.6 kg and the dimensions are 115 x 235 x 265 mm.

Comparison of Bruisometers

An initial exercise of the project was to compare the two bruisometers and choose which one is most appropriate for experimental and further development work.
Comparisons were made of both machine designs in terms of:-

- Ease of operation
- Effectiveness of applying a bruise

This information was collated and discussed with the new design teams at Coventry University who are working on the second generation of design for a mushroom bruisometer. Briefly, these points are:

- Design of spikes for holding/gripping mushroom is important. Conical spikes do not provide sufficient grip while parallel sided spikes with a short conical tip do provide grip.
- Application of the weight or force has to be made more convenient and less fiddly.
- The operation switch has to be robust and easy to use.
- The size of the test-head is important. It should be greater than 3 mm wide (for ease of viewing and measurement of the bruise) but less than 10 mm as the curvature of mushrooms resulted in an uneven width of force application.

All subsequent experiments were performed using only one of the prototype bruisometers. This is Bruisometer Two where the force is applied vertically by weights and the mushroom (held on spikes) is tilted by a pivoting table.

The Bruising Treatment

Mushroom stipes were trimmed to be level with the bottom of the caps. The caps were pushed stipe downwards to the spiked table. The bruise was therefore applied from one side through the top to the other side of mushroom. The bruise was applied through one of the two test-heads, (a) a 20 mm wide test-head, hemispherical in cross-section, and made of plastic (ABS) or (b) a 5 mm wide test-head, parabolic in cross-section, and made from polished metal (silver steel).

The test-head was carefully lowered onto the mushroom which was then rotated through 50° by means of the tilted table. The number of passes of the test-head on the surface of the mushroom could be varied.

After the bruising treatment, the mushrooms were held at 20°C in a high humidity chamber (c. 95% R.H.).

Bruise Colour Measurement

The colour of the bruise was measured using a Minolta meter (model CM-503i) with a 3mm viewing port. Unless otherwise stated, the colour was measured on the top of the mushroom.

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Minolta meter produces colour measurements as three types of colour, L, a and b.

L refers to the (whiteness or darkness of a colour). For statistical reasons, L is mathematically transformed to $\log_{10}(100\text{-}L)$ which is referred to as the degree of discolouration. The higher the figure means the more discolouration.

'a' and 'b' are known as opponent colour scales.

'a' when positive is the amount of red colour, and when negative is the amount of green colour.

'b' when positive is the amount of yellowness and when negative is the amount of blueness.

The results of the experiments below have been analysed by analysis of variance.

RESULTS

Experiment 1 - Can the bruisometer distinguish any possible differences in bruisability between mushrooms of different flushes. Effect of colour development time and weight.

Mushrooms were bruised with two passes using the large test-head. Two weights were compared, 150g and 180g. The bruise colour was measured after 4h and 7h after the bruising treatment. Two strains were compared, A12 and A15. Under these treatments, mushroom bruise colour was determined throughout the course of the crop.

Results

Analysis of the colorimeter results show that the higher weight (180g) resulted in significantly more bruising than the 150g treatment as degree of discolouration, redness (the 'a' parameter) and yellowness (the 'b' parameter) (Table 1). Under the conditions of this experiment, no difference could be found in the bruisability between strains A12 and A15 (Table 2). Extending the development time of the bruise from 4h to 7h resulted in higher redness and yellow readings but no significant difference in the degree of discolouration (Table 3).

When the bruising colour was measured during crop age, significant differences were found for degree of discolouration, redness ('a') and yellowness ('b') (Graph 1 (a, b and c)). The first flush mushrooms (1^{st} - 4^{th} Sept) showed most bruising colour, while the second flush mushrooms (10-11^{th} Sept) showed the least. The bruise colour of the third flush mushrooms was in between that of the first and second flushes.

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Table 1 - The effect of two bruise-weights on bruise colour (results of 4h and 7h colour development time and two strains combined)

	Degree of Discolouration	Redness	Yellowness
Bruise Weight	Log (100-L)	a	b
150g	0.981	1.035	9.704
180g	1.000	1.186	9.918
Significance	***	***	**

Table 2 - A comparison of the bruisability between two strains (results from the two colour development times and two weights combined)

	Degree of Discolouration	Redness	Yellowness
Strain	Log (100-L)	a	b
A12	0.989	1.118	9.865
A15	0.992	1.103	9.757
Significance	Ns	Ns	Ns

Table 3 - A Comparison of bruise colour 4h and 7h after bruising

	Degree of Discolouration	Redness	Yellowness
Time	Log (100-L)	a	b
4h	0.993	1.086	9.602
7h	0.987	1.137	10.04
Significance	Ns	***	***

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Conclusion

The conclusion of this first experiment is that the bruisometer design and conditions used (weights and number of passes) were able to demonstrate the differences in bruisability between flushes as experienced by the industry. This is the first quantification of this effect but more importantly it demonstrates the bruising action of the bruisometer is able to replicate this effect.

The experiment also illustrated that increased weight and to a lesser extent increased development time can lead to more bruising colour.

Experiment 2 - Can the bruisometer distinguish the bruisability between mushrooms of different strain and from different growing environment (humidity)

The bruisability was measured between four mushroom strains, each grown in conditions of either low humidity (75% RH) or high humidity (95% RH). Mushrooms were bruised by two passes of the large probe under a weight of 150g. Bruise colour was measured 4 hours after the bruising treatment. Bruise colour was followed during crop age.

Results

The different mushroom strains had significantly different amounts of bruising induced discolouration. I will refrain from quoting the results as (a) the differences varied depending on crop age and humidity and (b) this is from a single crop trial using two unusual humidities in the growing room and the results may not be representative of the strains in 'normal' conditions. A strain comparison would require greater replication (of crops) and more standard growing conditions.

The comparison of the effect of humidity on mushroom bruisability is best viewed from the point of view of crop age (Graph 2, (a), (b) and (c)). There was little effect of humidity on degree of discolouration or redress. However, on average the low humidity growing regime caused significantly more yellowing ('b' parameter) in the bruised area. This, however, was most pronounced in the early to mid crop (up to the 8th day of picking).

Conclusions

The conditions used for bruising were able to distinguish the bruisability between mushroom strains and different growing conditions.

Experiment 3 - What is the colour of bruised mushrooms offered for retail sale?

The two previous trials have shown that the bruisometer can distinguish the bruisabilities of mushrooms of different strains or agronomies. It was timely next to ascertain the extent of bruising-induced discolouration found available for retail sale. This could enable the conditions of bruising to be adjusted to more closely mimic the commercial situation. Twelve mushrooms were purchased from a supermarket in a town in Warwickshire. The mushrooms were deliberately chosen to be bruised. The colour of each mushroom was measured, once on the top and at four positions around the side.

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Table 4 Mushroom Colour of Bruised Mushrooms bought from a retail outlet.

		Degree of Discolouration $\log_{10}$ (100-L)	Redness 'a'	Yellowness 'b'
Mushroom Top	Average	1.176	3.55	17.47
	Maximum	1.355	5.71	21.64
	Minimum	0.911	0.22	12.12
Mushroom Side	Average	1.276	4.98	19.25
	Maximum	1.420	7.15	23.44
	Minimum	1.063	2.47	13.13

The colour data presented in Table 4 show the average colour of the bruised mushrooms and also the maximum and minimum data. The maximum results represent areas of severe bruising while the minimum represents areas of little bruising or where the viewing port of the colorimeter was over an unbruised area. These data will be used for future experiments to determine the specifications for the use of the bruisometer (e.g. weight applied, number of passes, and colour development time). A comparison of the average colour data from the tops of bruised mushrooms with the data from experiments 1 and 2 reveals that the bruise colour from experiments 1 and 2 is well below that found commercially. As a result, the smaller probe (5 mm width) was used for all subsequent experiments as it can apply a greater force per unit area and hence a stronger bruise colour.

Experiment 4 - Effect of Bruising Weight and Number of Bruising Passes on Bruise Colour (on HRI grown mushrooms)

Mushrooms (A15) were grown at HRI-Wellesbourne under standard conditions and harvests were made from the first three flushes. Mushrooms were subject to one of a range of bruising treatment combinations:- Four weights (60g, 105g, 150g, and 195g) X four different pass numbers (two, three, four or five passes). The bruising was done with the small probe. Bruise colour was measured after 2h on the top of the mushroom. Five mushrooms were examined per flush per treatment combination.

Results

Graphs 3 [(a), (b) and (c)] and Photograph 3 show the effect of bruising weight and pass number on the degree of discolouration, redness and yellowness. For all three types of colour data, clear relationships can be observed. The degree of discolouration, redness and yellowness all increase with increasing number of passes and increasing weight. There appears to be a linear relationship between pass number and colour. However, for the

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weights, there is the suggestion that the higher weights might be resulting in the maximum bruise colour. The evidence for this is the closeness of the lines of 150g and 195g treatments for redness (Graph 3(b)) and yellowness (Graph 3 (c)).

Conclusion

The conclusion of this experiment is that the extent of bruising can be influenced by the conditions used in the experiment (i.e. weight and number of passes). Care must be taken in choosing these conditions. A too heavy bruise may be outside the range that is observed commercially and may be so severe as to obscure any real differences in bruisability between mushrooms. A too light bruise may be so light as to not reveal real differences in bruisability and may be so light that the colour may be difficult to observe.

Experiment 5 - Time-course of Bruise Colour Development on commercially grown mushrooms

Mushrooms very carefully harvested from a growing house at Monaghan-Middlebrook farm in Avon. They were of the same flush, strain and agronomy. Using small probe the mushrooms were subjected to one of three bruising treatments: 105g and three passes, 150g and four passes or 195g and five passes. Bruise colour was measured after 1 hour and then every half hour for 4 hours. Different mushrooms were used for each measurement to avoid the risk of possibly measuring damage caused by the colorimeter itself. Ten mushrooms were measured per bruising treatment - time combination.

Results

Graphs 4 [(a), (b) and (c)] show the effect of development time on bruise colour for the three bruising treatments. The degree of discolouration increases over the time course although there is the suggestion that the colour may be reaching a maximum towards the end of the time-course. The effect of the three bruising treatments are significantly different from one another, 195g x 5 passes treatment producing the greatest discolouration, followed by 150g x 4 passes treatment and then the 105g x 3 passes treatment.

The redness data also increased over time (Graph 4 (b)) and showed signs of plateauing at the end of the time course. No significant difference was found between the 105g x 3 passes treatment and the 150g x 4 passes treatment, although for the 195g x 5 passes treatment the bruise area was significantly redder.

The yellowness data is shown in Graph 4 (c). There is no evidence of any significant change in yellowness during the time course.

Conclusion

The colour of the bruise area changes over time. Therefore any possible future use of the bruisometer would require a fixed duration of time between bruising and observation. Conversation with Brian Oxley of how he might want to use the bruisometer commercially suggests that a relatively short period of time would be preferable for commercial use (e.g. 1 or 2 hours).

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Experiment 6 - Effect of Bruising Weight and Number of Bruising Passes on Bruise Colour on Commercially Grown Mushrooms

Mushrooms were harvested from a single growing house from the Monaghan-Middlebrook farm at Avon. Using the small probe the mushrooms were subjected to a variety of bruising treatment combinations: four different weights (60, 105, 150 or 195g) x five pass numbers (1, 2, 3, 4, or 5). The colour in the bruise area was measured after 2 hours.

Results

Graphs 5 (a), (b) and (c) show the effect of bruising weight and pass number on bruise colour. All three measures of colour (degree of discolouration, redness and yellowness) show that bruise colour is significantly more intense with increasing weight and increasing pass number. The effect of weight is however less pronounced on yellowness.

Conclusion

The results of the Monaghan-Middlebrook grown mushrooms confirmed those of the HRI-grown mushrooms that bruise weight and pass number have major effects on bruise colour. For the bruisometer to be of practical use, specifications must be chosen which result in a bruise colour within an hour or two, comparable to that found commercially. It was decided to recommend to the new design teams at Coventry University that the latest prototypes should (a) have a probe of 7.5mm width, (b) deliver two or four bruising passes (from a single switch operation) and (c) have weights of up to 300g.

Experiment 7 - Can the Bruisometer distinguish the bruisability of calcium chloride treated mushrooms

This series of experiments on the bruisometer took place at approximately the same time as the experiment funded by HDC to investigate the use of calcium chloride solution to improve mushroom quality (M 37). It was decided to perform an extra experiment to find whether the bruisometer could identify differences in the bruisability of the differently treated mushrooms. A full description of the calcium chloride experiment is given in the report of project M37. Briefly, the experiment consisted of a crop of mushrooms and the trays were given one of seven watering treatments: - Treatment 1 - demineralised water (virtually calcium free); Treatment 2 - tap water (0.004% Ca); Treatment 3 - 0.1% Ca; Treatment 4 - 0.2% Ca; Treatment 5 - 0.3% Ca; Treatment 6 - 0.4% Ca; and Treatment 7 - 0.5% Ca. The mushrooms were of strain A15, the second and third flush mushrooms were bruised with the small probe by 195g and 2 passes. The colour was measured 4 hours after the bruising treatment.

Results

The only major significant differences in bruise colour were found with the degree of discolouration. Table 5 shows the effect of calcium chloride irrigation treatment on the degree of discolouration. There is a significant effect of calcium chloride irrigation on bruise discolouration. Calcium chloride causes the mushroom bruise to be less significantly discoloured at the higher concentrations (0.4% and 0.5%). Whether this is significant from the point of view of perception by the consumer and benefit to the industry is discussed in the

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report of M 37. More importantly for this project, this experiment has demonstrated that the bruisometer can identify differences in mushroom bruisability.

Table 5 - The effect of calcium chloride irrigation on bruise colour. The Least Significant Difference (at 5% level) is 0.050 and can be used for comparing the degree of discolouration of the calcium chloride treated mushrooms with the water treated mushrooms for each flush. Note that for both flushes the values for 0.4% and 0.5% $CaCl_2$ are significantly lower than the water values (i.e. the difference is greater than 0.050).

	Degree of Discolouration					
	Water	$CaCl_2$%				
		0.1	0.2	0.3	0.4	0.5
Second Flush	1.279	1.198	1.239	1.250	1.208	1.221
Third Flush	1.178	1.206	1.167	1.147	1.118	1.103

Conclusions

1. The bruisometer design based on vertical weights was easier to use than the spring-based bruisometer. Design features from both bruisometers which were beneficial, were identified for incorporation into the next generation of designs.

2. The bruisometer has been validated. It has been demonstrated that it can distinguish between mushrooms of different bruisabilities (crop age, flush number, strain, calcium chloride or water irrigation). The bruisometer therefore has the potential of being a valuable and novel quality assessment tool.

3. Bruise colour was made more intense by weight of bruise, number of bruising treatments and time left between bruising and observation.

4. Specifications of use were identified and transmitted to Coventry University where the next generation of prototypes are currently being designed and built. The bruisometer should (a) have a probe of 7.5mm width, (b) deliver two or four bruising passes and (c) have weights up to 300g.

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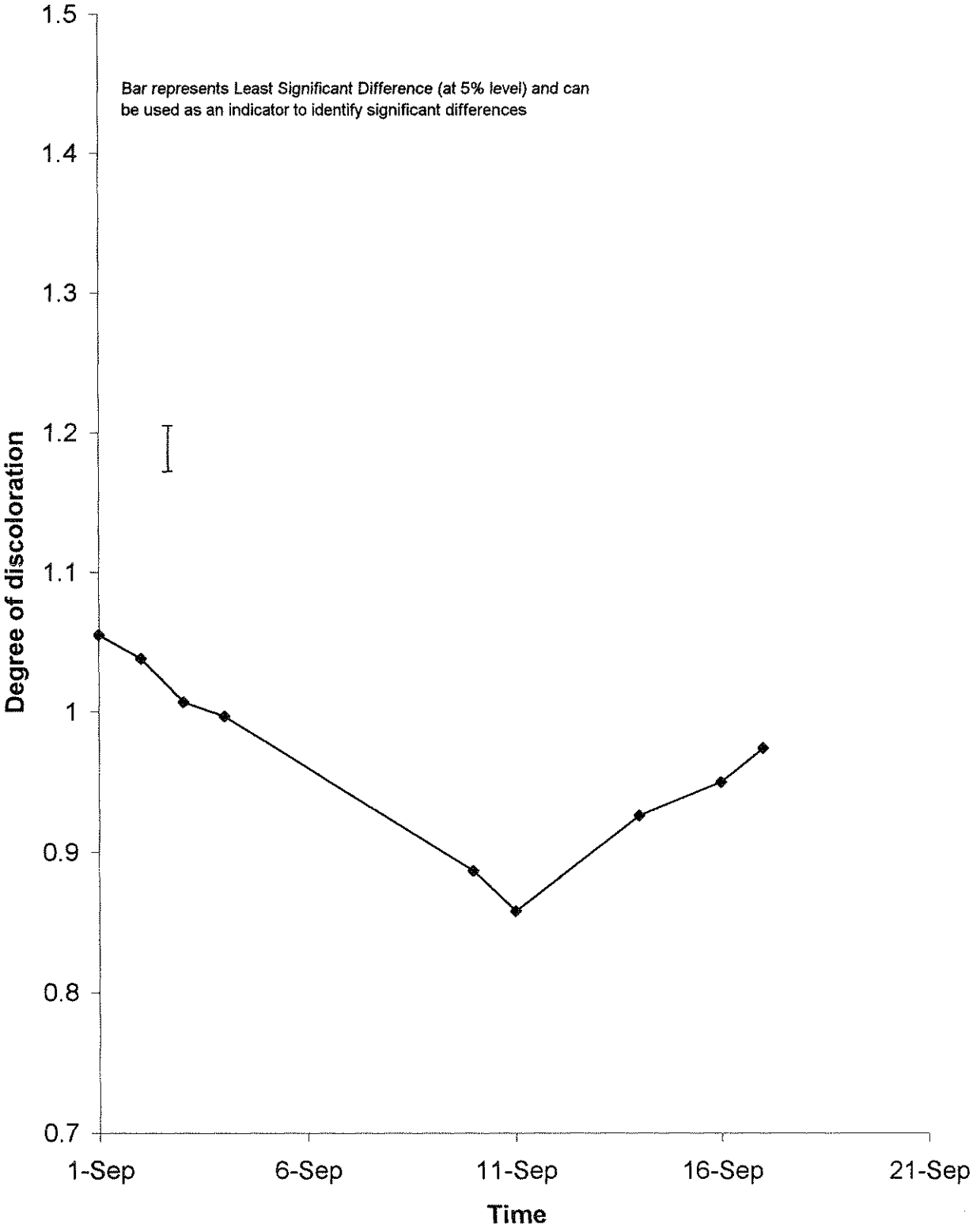
Graph 1(a) - Changes in bruise colour (degree of discoloration) during crop age

Mushrooms bruised with the 20mm test-head



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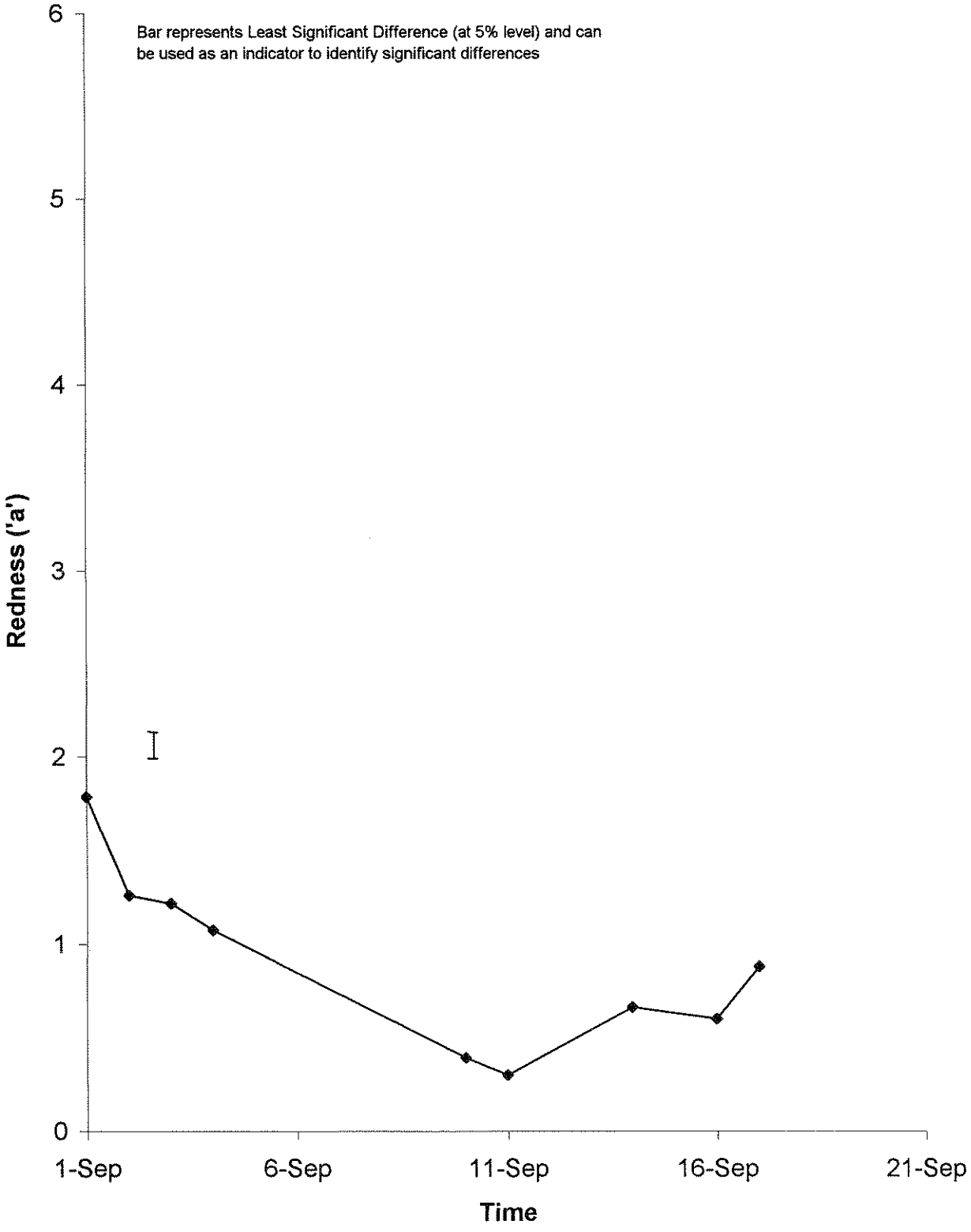
Graph 1(b) - Changes in bruise colour (redness 'a') during crop age

Mushrooms bruised with the 20mm test-head



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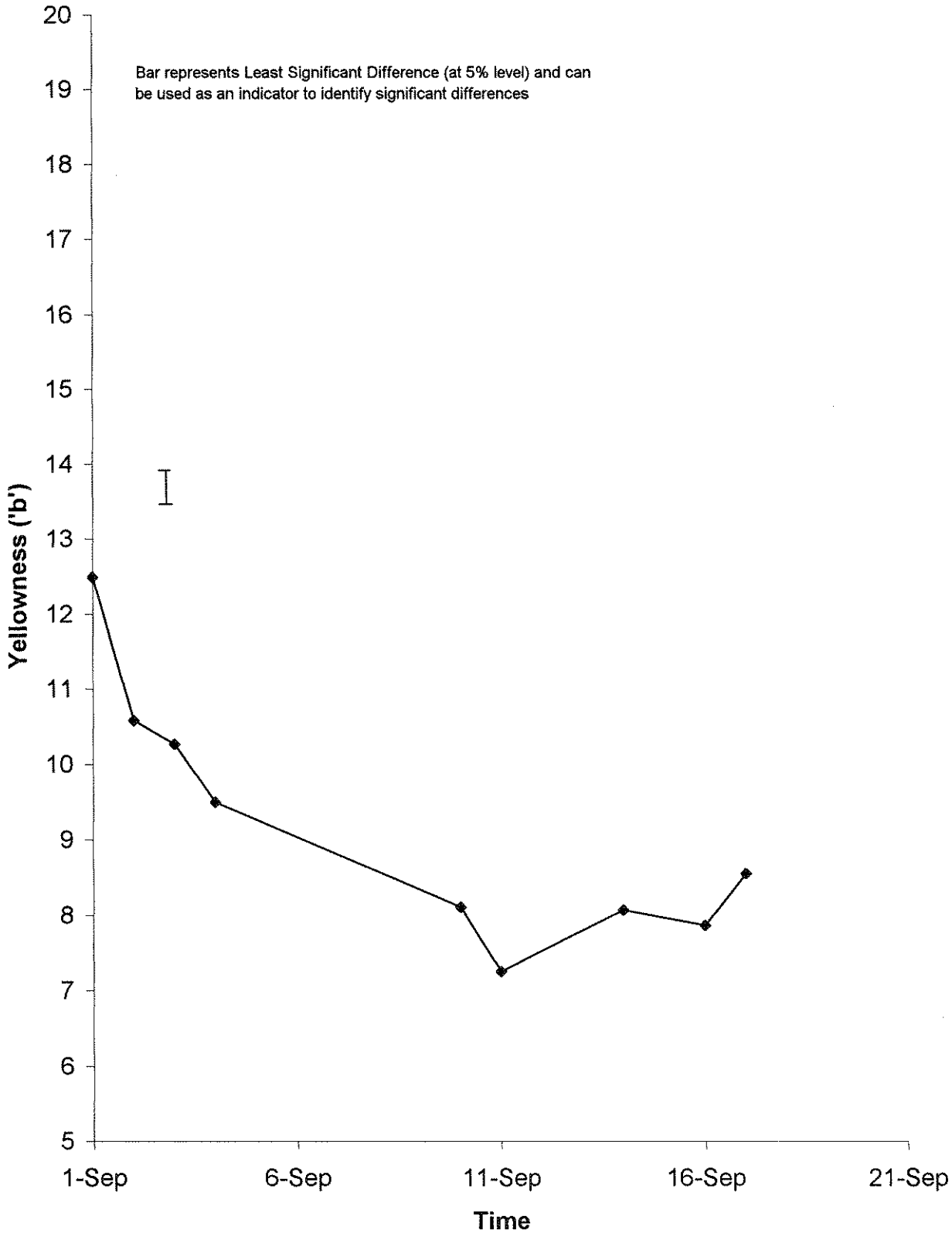
Graph 1(c) - Changes in yellowness ('b') during crop age
Mushrooms bruised with 20mm test-head



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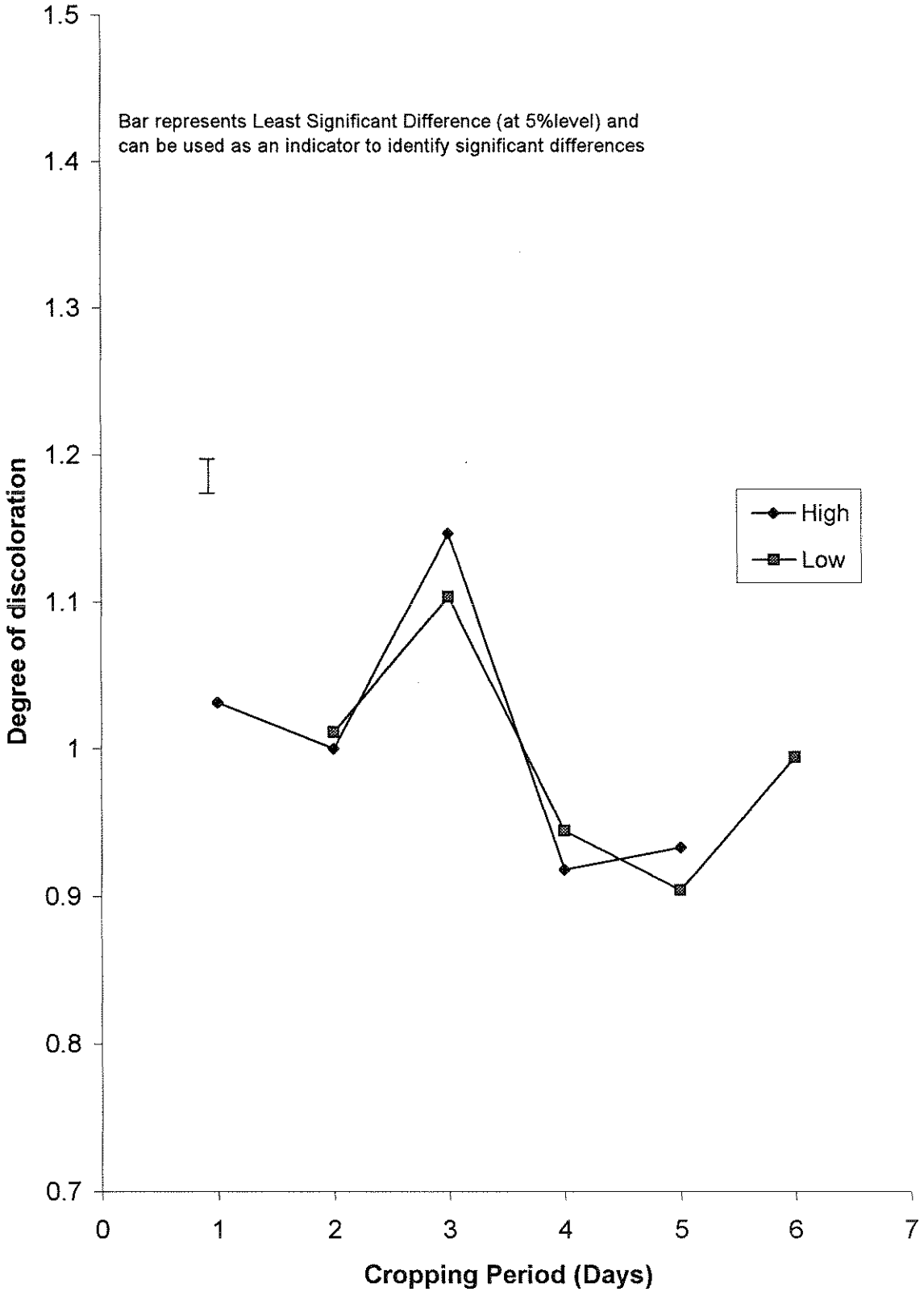
Graph 2(a) - The effect of high and low humidity on degree of discoloration during crop age

Mushrooms bruised with the 20mm test-head, two passes and a weight of 150g.



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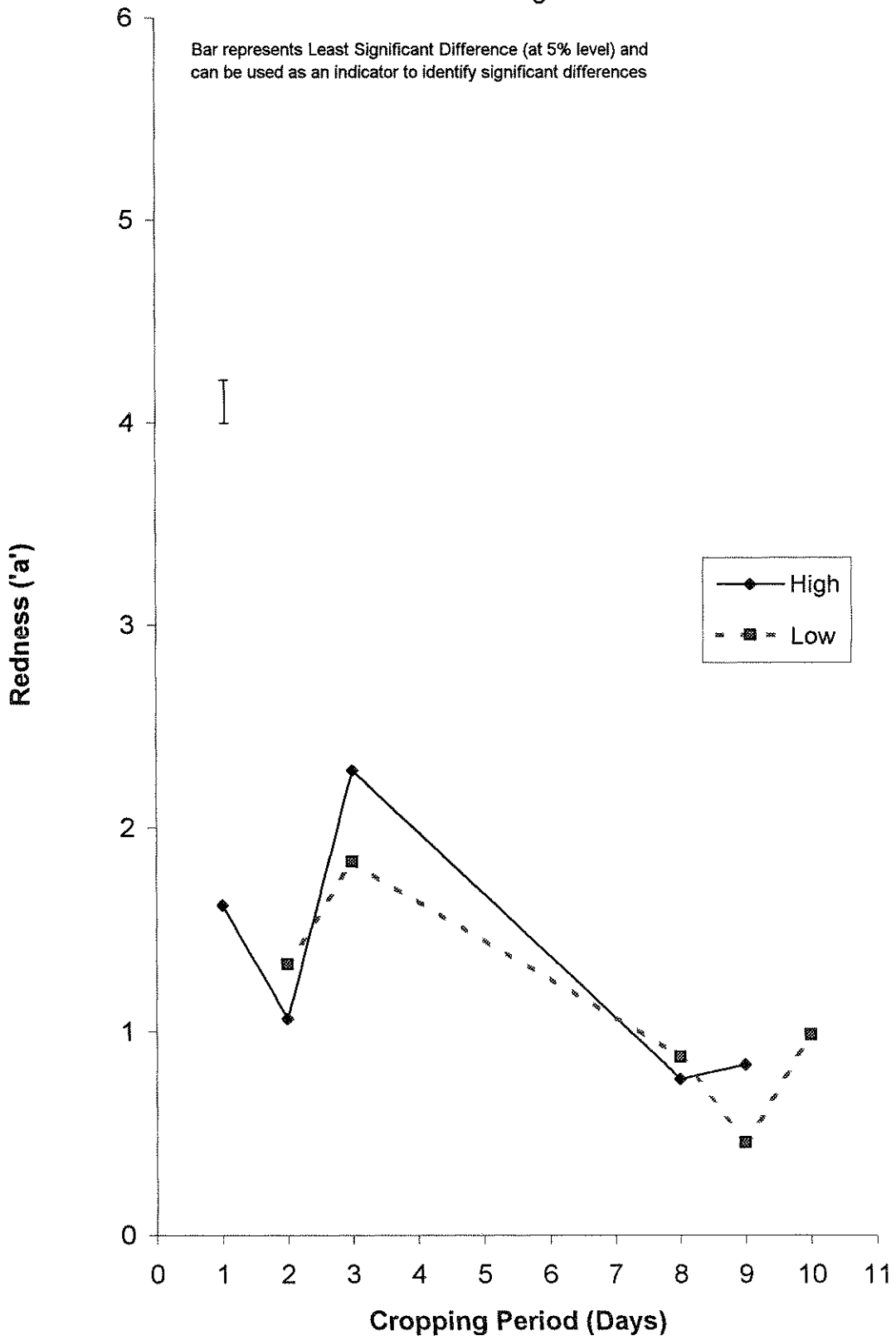
Graph 2 (b) - The effect of high and low humidity on redness ('a') during crop age

Mushrooms bruised with the 20mm test-head, two passes and a weight of 150g.



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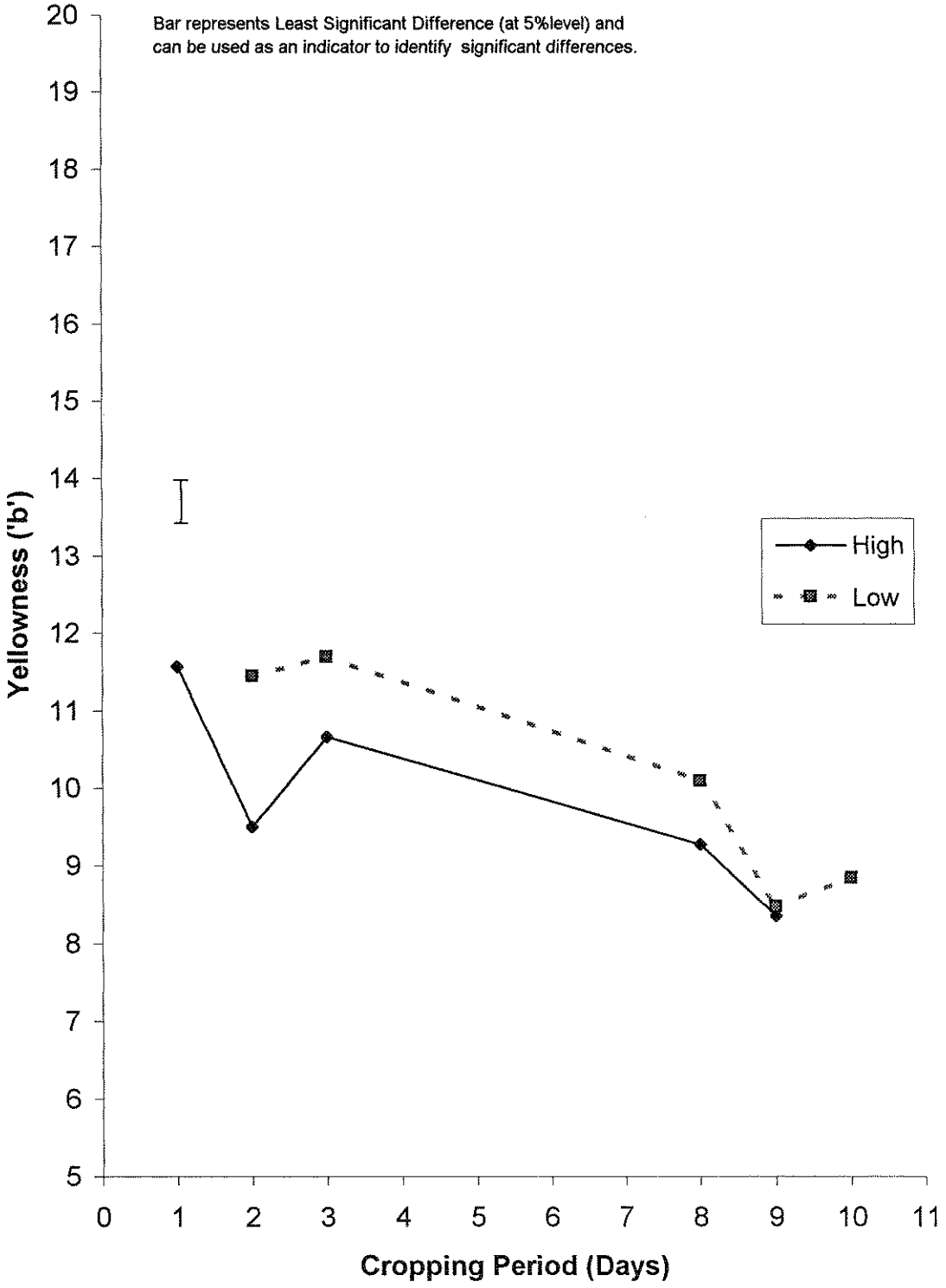
Graph 2(c) - The effect of high and low humidity on yellowness ('b') during crop age

Mushrooms bruised with 20mm test-head, two passes and a weight of 150g.



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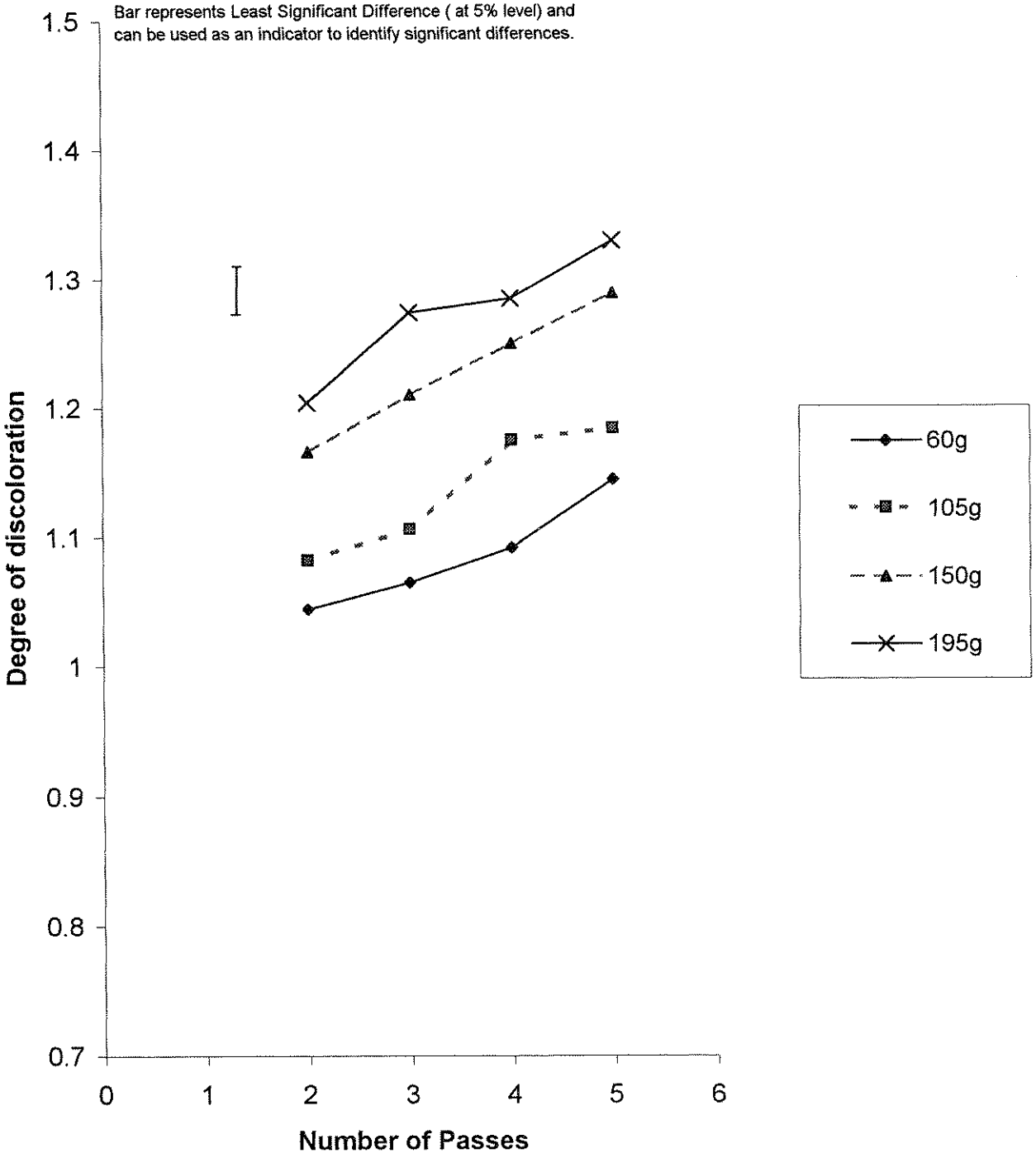
Graph 3(a) - Effect of bruise weight and number of bruise treatments (passes) on degree of discoloration in a HRI grown crop

Mushrooms bruised with the 5mm test-head. Colour measured after 2 hours.



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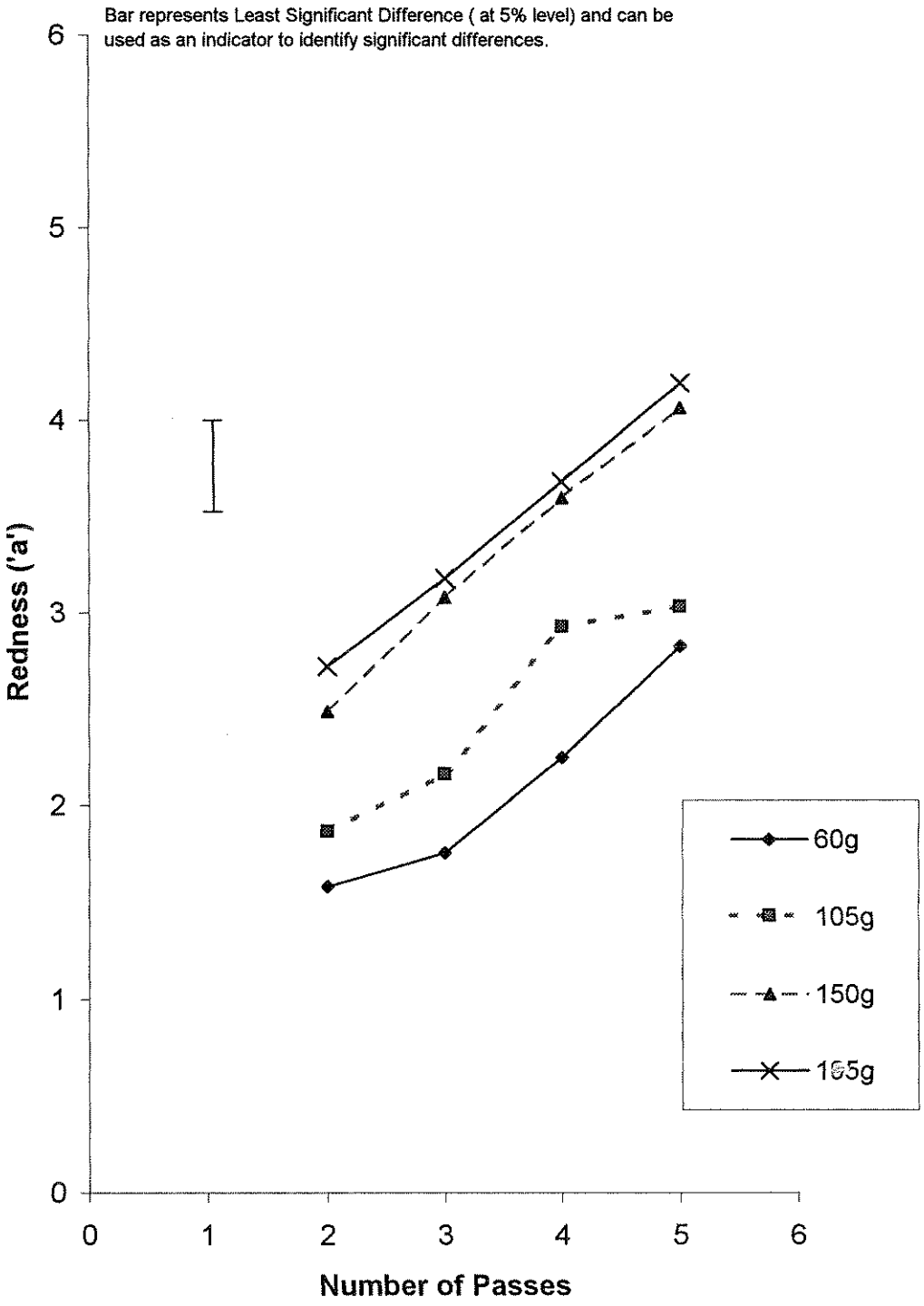
Graph 3 (b) - Effect of bruise weight and number of bruise treatments (passes) on redness ('a').

Mushrooms bruised with 5mm test-head. Colour measured after 2 hours.



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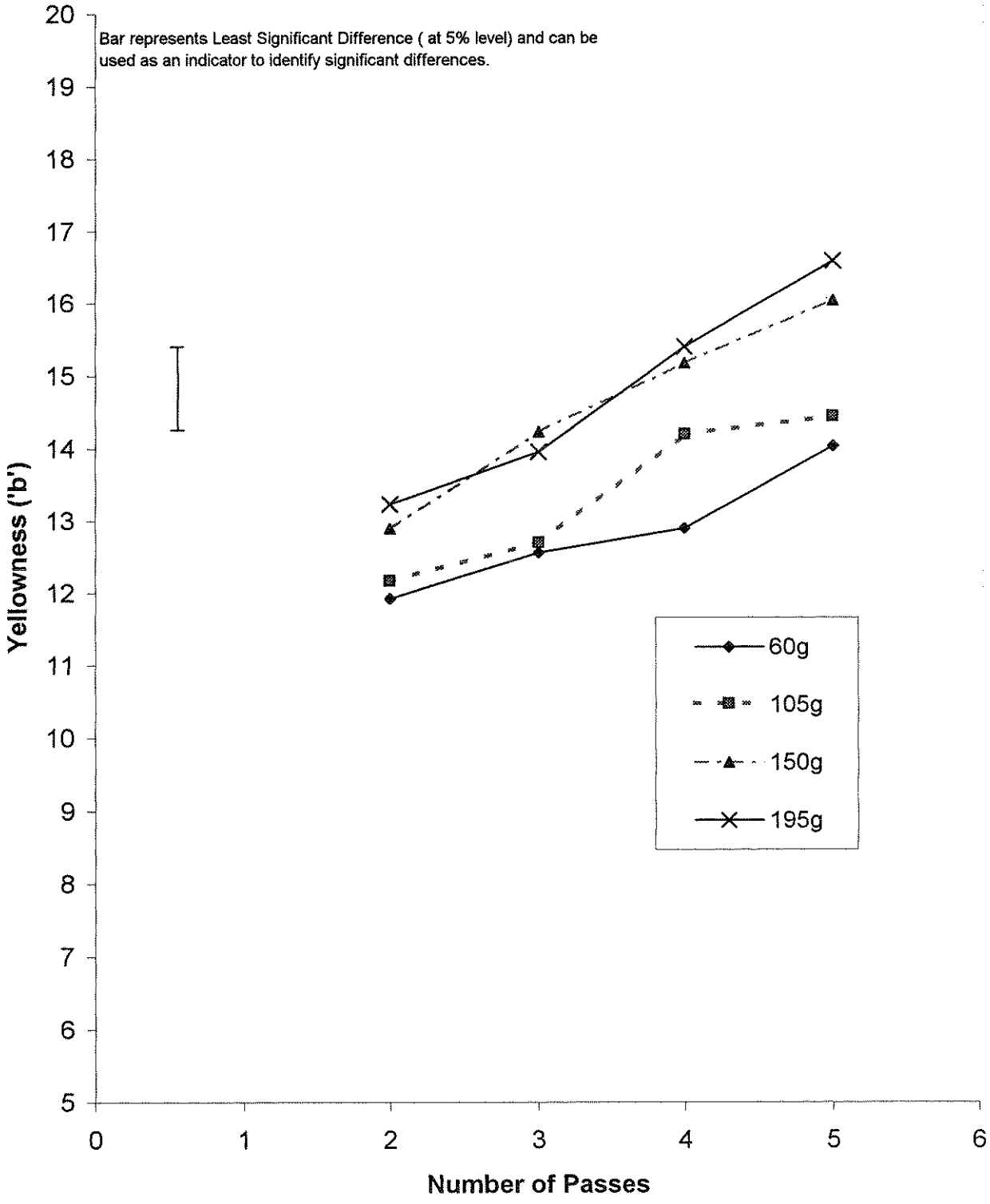
Graph 3 (c) - Effect of bruise weight and number of bruising treatments on yellowness ('b') in a HRI grown crop

Mushrooms bruised with 5mm test-head. Colour measured after 2 hours



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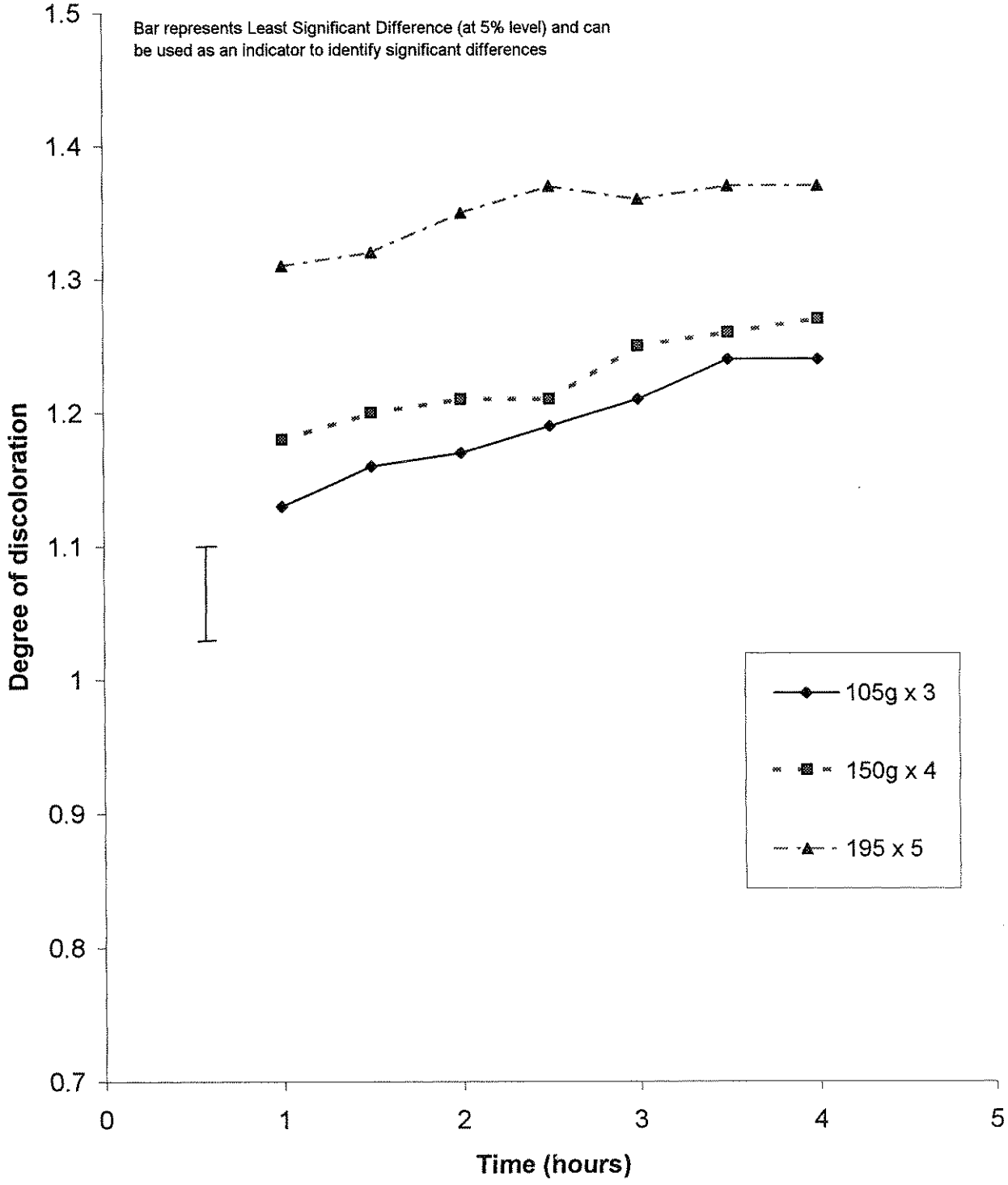
Graph 4 (a) - Effect of bruise development time on the degree of discoloration for three bruising treatments

Mushrooms bruised using 5mm test-head



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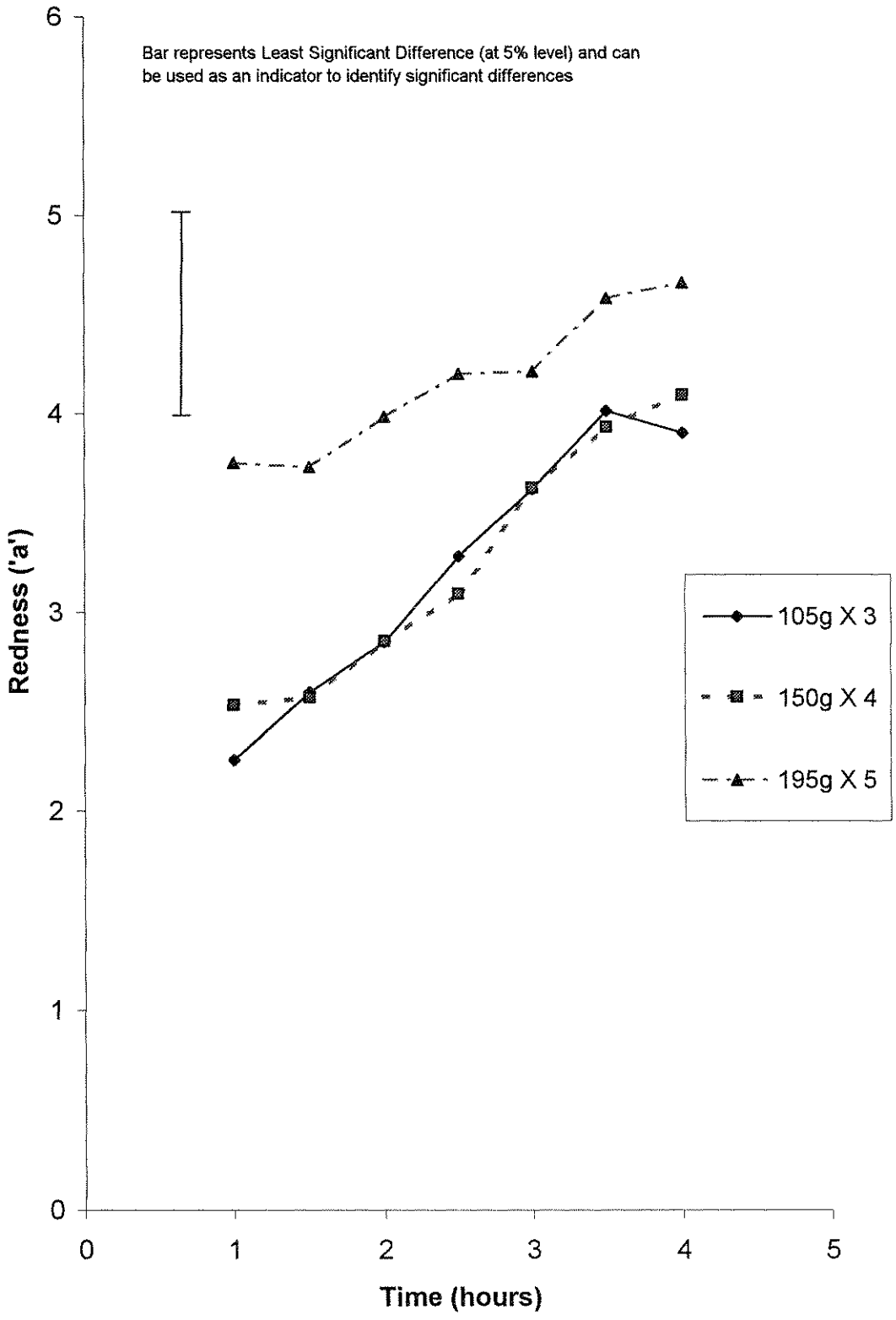
Graph 4 (b) - Effect of bruise development timen on redness ('a') for three bruising treatments

Mushrooms bruised using 5mm test-head



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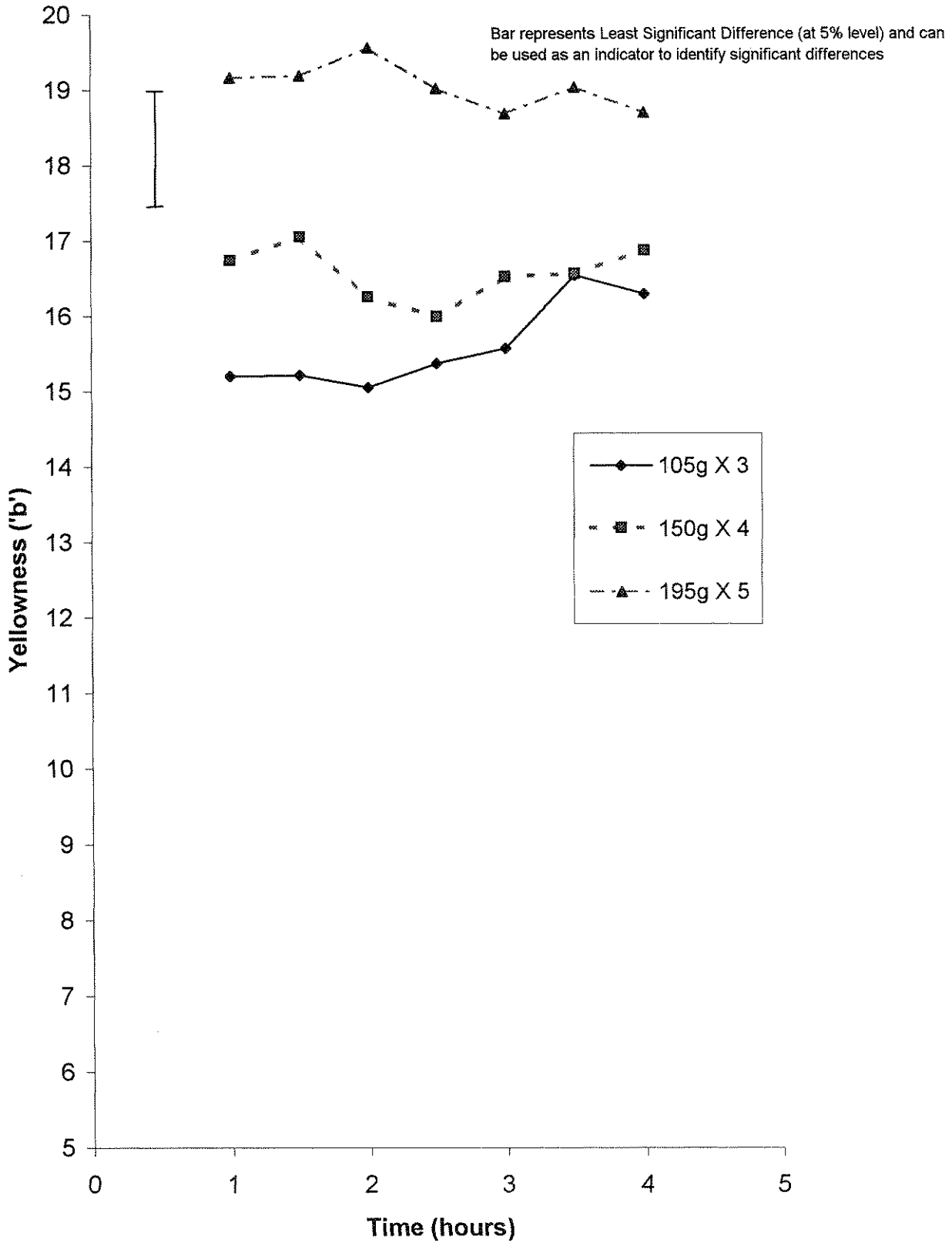
Graph 4 (c) - Effect of bruise development on yellowness ('b') for three bruising treatments

Mushrooms bruised by 5mm test-head



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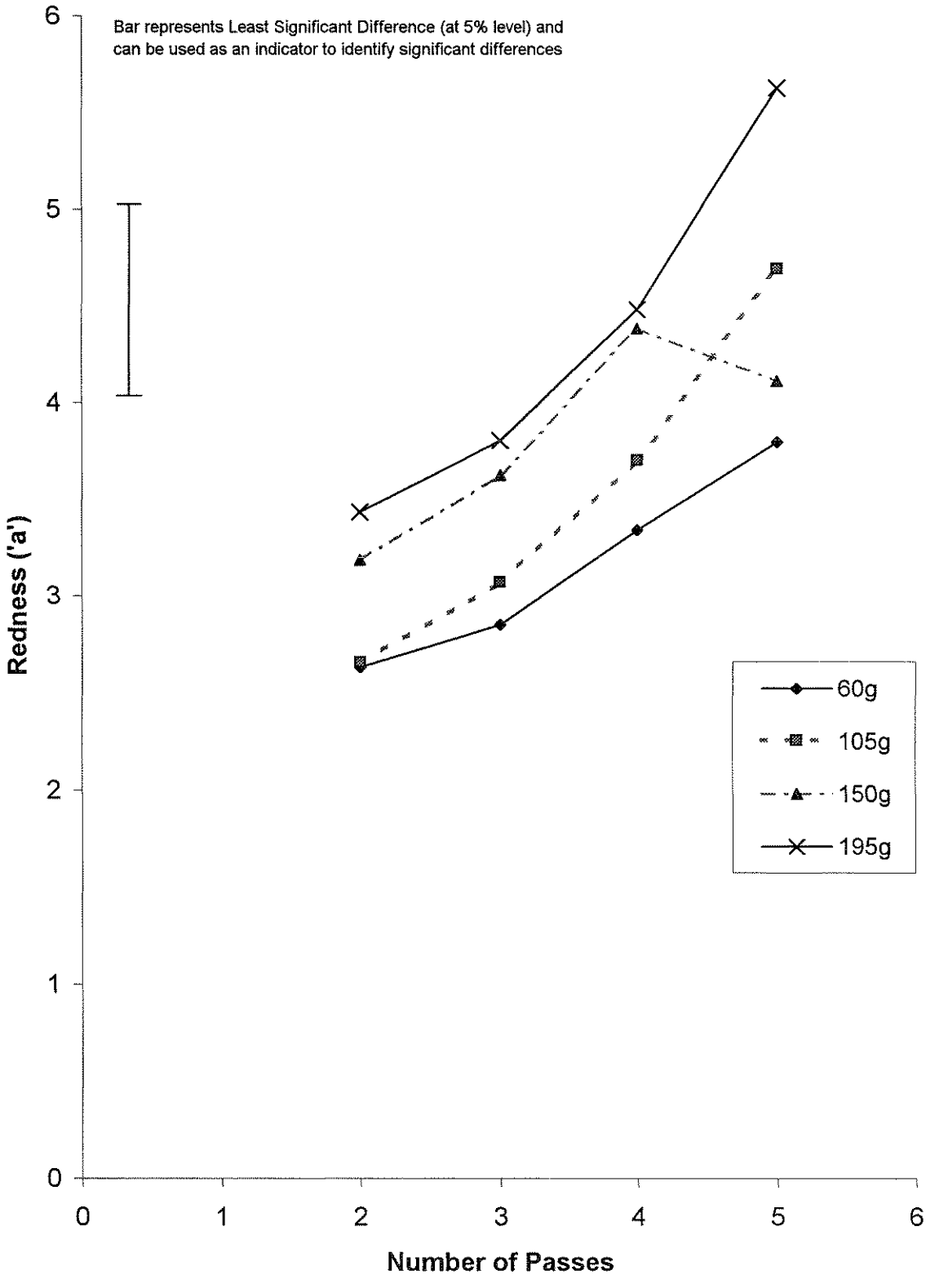
Graph 5 (b) - Effect of bruise weight and number of bruising treatments (passes) on bruise colour (redness - 'a') in a commercially grown crop

Mushrooms bruised by 5mm test-head. Colour measured after 2 hours.



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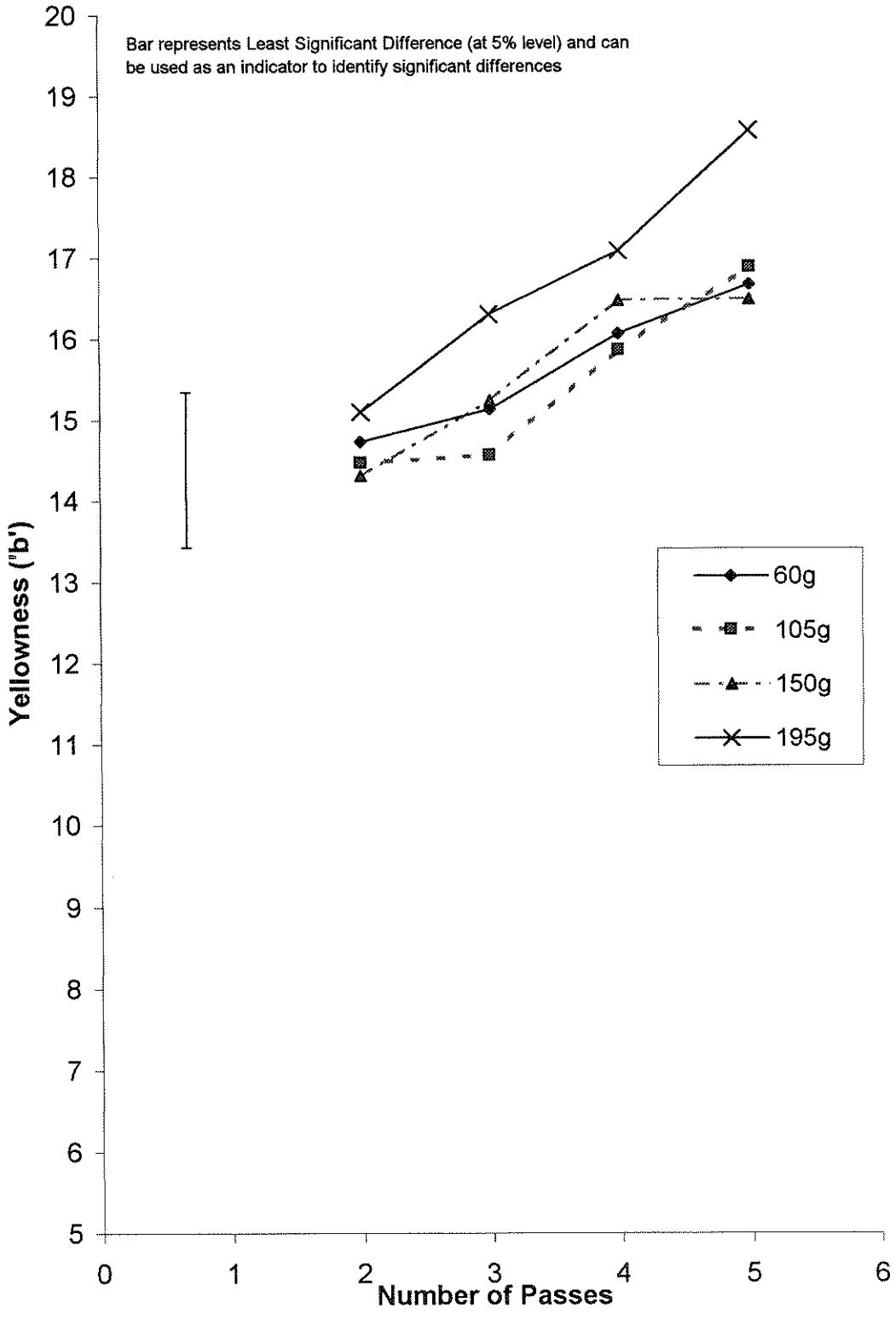
Graph 5 (c) - Effect of bruise weight and number of treatments (passes) on bruise colour (yellowness -'b') in a commercially grown crop.



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