Screening of *Agaricus bisporus* (Lange, Imbach) Strains and the Casing Variables for Quality Mushroom Production in Spain

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Abstract. Production and quality parameters of three commercial strains of cultivated mushroom *Agaricus bisporus* (Lange, Imbach) were evaluated. A correlation matrix was made between the main parameters. Blancochamp BL-40, a smooth white hybrid, generally produced the greatest number of mushrooms and provided the highest yield, and its firm mushrooms showed high protein, dry matter, and soluble solid content. Pla 8.9, a midrange hybrid type, produced mushrooms with a high protein, soluble solid, and ash content. The third strain assayed was Gurelan 45, which produced large, firm off-white mushroom crops. A correlation matrix was made between the main parameters. In regard to the other parameters considered, no strain stood out from the others. The Rioja-type casing produced the greatest number of mushrooms, although these were smaller and harvested earlier than those produced in other casing mixtures. Soil without additives produced the largest mushrooms, which also had a higher dry matter content, were firmer, and contained more soluble solids. The other casing materials, binary mixtures of soil with *sphagnum* or black peat, produced mushrooms of intermediate values. The correlation matrix showed that the higher the number of mushrooms, the greater the overall yield, the smaller the size, and the earlier the first flush. It was also observed that a higher content in dry matter was correlated with firmer texture, greater contents in soluble solid and protein, and lower pH and ash content.

Fungi have been viewed with scepticism, reserve, and prejudice since primitive times (Tseng and Luong, 1984). They were being consumed in ancient China 3000 years ago and were even considered a source of immortality in ancient Egypt. The Greeks and Romans knew them for their delicious aroma and taste, but it was not until the 18th century in France that the first serious attempts were made to grow mushrooms [*Agaricus bisporus* (Lange) Imbach] commercially. A technique for a short method of composting and the use of synthetic composts was introduced at the beginning of the last century (Tseng and Luong, 1984). At present, mushrooms are cultivated in 80

countries of the world with a production of 6.3 MT in 1997, of which 31.7% corresponded to *A. bisporus* (Courvoisier, 1999). The European Union with 45.7% of world production (mainly Holland and France), North America (24.9%), and Asia (20.7%) are the main production regions (ANICC, 1995).

At present, four clearly differentiated commercial mushroom strains exist on the market: 1) pure white strains, characterized by their white and relatively small fruit bodies without scales; 2) off-white strains with large white mushrooms with often dark scales on the cap; 3) hybrid strains, the most widely cultivated and resulting from a cross between the previously mentioned strains, which produce high yields and good quality; and 4) brown strains with a brownish to pale-colored cap (Fritsche and Sonnenberg, 1988). However, the actual cap characteristics of these strains regarding size, shape, and color are strongly influenced by environmental and cultivation conditions (Tschierpe, 1983).

The production and quality parameters of most interest are: number, size, earliness, freshness, color, shape, firmness, aroma, freedom from debris, the degree of maturity

and development stage, and visual defects (Burton, 1989; Burton et al., 1995; Carey and O'Connor, 1991; Pardo, 1999). Any change in one or more of these factors may affect acceptability by the consumer. Like with most horticultural products, mushrooms have a limited storage life (1 to 3 d at 18 °C) and that quality is affected by cultivation techniques, the strain, handling, and storage conditions (Burton, 1989).

In mushroom cultivation, the casing material plays a very important role because it conditions the stage of fructification. The casing has several functions because, among others, it: 1) constitutes the physical medium that supports the sporophores; 2) maintains an adequate degree of moisture; 3) provides a suitable medium for stimulatory bacteria; 4) protects the compost surface from drying out; 5) provides the mycelium with an aerated environment, facilitating gas exchange; and 6) provides an environment with a low osmotic value (Bazerque and Laborde, 1975; Visscher, 1988; Wuest and Beyer, 1996). The most widely used casing is, without doubt, *sphagnum* peat because of its high water-retaining capacity and excellent structural characteristics (Yeo and Hayes, 1979). Different types of soil have also been widely used with good results, the main properties needed being a good structure and a minimum of 5% organic matter (Edwards, 1974; Hayes, 1978; Pizer and Leaver, 1947). Such mineral materials are usually combined with different organic substrates, mainly peat, which act as structural and water-holding correctors.

In Spain, there are two main mushroom-growing areas (Castilla-La Mancha and La Rioja-Navarra), which are responsible for almost all the mushrooms grown and each area tends to use its own casing materials. In Castilla-La Mancha, growers use soils of different origins to which peat is added, and in La Rioja-Navarra, a fine lime gravel combined with brown peat is used.

During the present study, we have evaluated the production (number, yield, unitary weight, and earliness) and quality (color, dry matter, texture, protein and soluble solids content, ash, and pH) of three commercial mushroom strains (Pla 8.9, Blancochamp BL-40, and Gurelan 45) grown in four casings (soil, soil + *sphagnum* peat, soil + black peat, and the casing usually used in La Rioja). A correlation matrix has been presented among the principal production and quality parameters.

Our aim is the agronomic evaluation of different casing layers used in mushroom cultivation.

Materials and Methods

Mushroom cultivation and experimental design. The experiment was carried out in the Centro de Investigación, Experimentación y Servicios del Champiñón (Quintanar del Rey, Cuenca, Spain) using an Ibercex experimental walk-in growth chamber (ASL, S.A., San Fernando de Henares, Madrid, Spain) provided

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with a humidification system, a heating/cooling system, and internal air circulation/outside ventilation. In this way, the temperature, relative humidity, and carbon dioxide levels were controlled automatically.

The experimental design used was a 3 × 4 Equilibrated Factorial Plan with eight replicates (randomized blocks with two factorial factors). The first factor, with three levels, was the strain type. The second factor, with four levels, was the casing type. Thus, 32 experimental trays, eight for each casing, were used for each strain. The experimental trays (16 L in volume, 870 cm² in area) were filled with 6 kg of pressed compost (450 kg·m⁻³).

Mushrooms strains. Three commercial strains of *Agaricus bisporus* mushroom were analyzed as the representatives of main cultivated types in Spain. They were 1) Pla 8.9 (midrange hybrid) supplied by Pla Micelios de Champiñón y Setas, S.A.T. (Arganda del Rey, Madrid, Spain); 2) Blancochamp BL-40 (smooth white hybrid) supplied by Micelios Blancochamp, S.L. (Valverde de Júcar, Cuenca, Spain); and 3) Gurelan 45 (large off-white hybrid) supplied by Gurelan, S.C. (Huarte-Pamplona, Navarra, Spain). Spawn was added at the rate of 12 g·kg⁻¹ pasteurized mushroom compost.

Compost and casing mixtures. A semi-synthetic cereal straw-based compost procured from Champy-Rey, SL, Quintanar del Rey, Cuenca, Spain, was used. The straw compost characteristics were: moisture 67.6%, organic matter 75.27%, total nitrogen (N) 2.28%, and carbon/N ratio 19:1; pH 7.34 and ash content 24.73% were adjusted within the optimal range for mushroom cultivation (Hearne, 1994; Pardo, 1993; Vedder, 1978).

Four casing mixtures were assayed: 1) soil with no additives extracted from “La Cerrasa” (Villanueva de la Jara, Cuenca, Spain) at a depth of 3 to 4 m and supplied by Oviedo Soler Hnos, S.L. (Cuenca, Spain); 2) binary mixture (4:1 v/v) of soil and brown *sphagnum* peat supplied by Projar, S.A. (Valencia, Spain); 3) binary mixture (4:1) of soil and black peat supplied by Industrias Fertilizantes Orgánicas, S.A. (Valencia, Spain); and 4) a typical casing from La Rioja obtained by mixing a fine limestone quarry gravel with blond *sphagnum* peat (Peña and Sanz, 1993) and supplied by Gohercu, S.L. (Quel, La Rioja, Spain). The casing was applied in a 3-cm layer (2.6 L per tray).

Cultivation cycle. The growth cycle was carried out according to the growth chamber conditions (air temperature, relative humidity, and carbon dioxide concentration) within the ranges suggested for the selected strains (CIES, 2007). A spawn run period of 14 d was used, and the usual disinfectant (formalin, 18 mL·m⁻²), insecticide (diflubenzuron 25%, 3.6 g·m⁻²), and fungicide (prochloraz 46%, 0.62 g·m⁻²) treatments were applied after casing. The casing was deeply raked after 7 d of casing run, and ventilation was carried out 11 d after casing to stimulate primordia formation. The total growth cycle

lasted 80 d so that five flushes of mushrooms were harvested.

Yield and production parameters. Mushrooms were harvested daily at their optimal commercial stage of development, corresponding to morphogenetic Stages 2, 3, and 4, according to the classification established by Hammond and Nichols (1976).

To calculate yield, expressed as kg·m⁻², the quantity of mushrooms produced daily in each tray was weighed before stipe trimming with an accuracy of 1 g.

Mushrooms were counted and separated according to size and defects into three groups: large mushrooms (40 mm or greater); medium mushrooms (15 to 40 mm); and mushrooms with defects in size, color, or disease symptoms (nonmarketable production).

The mean size of individual mushrooms (g) was determined. Earliness was expressed as the number of days elapsing between casing and the harvesting of the first flush.

Quality parameters. For this evaluation, mushrooms of uniform size and maturity were used. These were picked on the day of maximum production during the first three flushes. For the overall evaluation of each parameter, the mean weight was calculated for the relative yield of each of the first three flushes.

The surface color of the mushrooms was measured by reflection using a Minolta CR-300 colorimeter (Minolta Camera Co., Ltd., Osaka, Japan) calibrated with a CR-A43 calibration plate ($L^* = 96.12$, $a^* = -0.11$, $b^* = +2.66$) and illuminant D₆₅. Four measurements were made on the caps of five uniformly sized, disease-free mushrooms (20 measurements in all) taken from the first three flushes and for each tray. Of the four measurements, one was made in the center of the cap and the others at distances between 1 and 2 cm depending on the size of the carpophores. The chromatic coordinates, L^* (brightness) and b^* (yellow–blue component), and the chromatic attribute ΔE^* , which measures the deviation compared with the other values of an ideal sporophore, were used (Roy et al., 1995).

The dry matter content, expressed in g·kg⁻¹, the weight loss after desiccation at 105 °C in a forced-air oven (Selecta, Digitec model; J.P. Selecta, S.A., Abrera, Spain), was calculated (MAPA, 1994).

To evaluate the mechanical properties of mushrooms in terms of texture (firmness), the force of compression until the rupture point was determined. Puncture tests were performed using a penetrometer (Fruit tester PT 011; Bertuzzi, Alfonsine, Italy), which is based on the principle of the Magness-Taylor firmness tester, with a cylindrical punch of 6.4-mm diameter. The results are expressed as rupture force (Newtons). Four measurements on the caps of five mushrooms, one in the center of the cap and three between 1 and 2 cm from this point, depending on the size of the fruit bodies, were made for each of the first three flushes.

The protein content of the carpophores, expressed in g·kg⁻¹, was calculated by multiplying the total N content by a conversion factor of 4.38 (Delmas, 1989). Total N was determined by Kjeldahl's method (MAPA, 1994; TECATOR, 1987) using a Tecnic Model D-12 digester (Tecnología Ibérica de Laboratorio, S.L., Madrid, Spain) and a Kjeltex Model 1030 automatic analyser (Tecator AB, Höganäs, Sweden).

A digital refractometer (Atago, Model Palette PR-100; Atago Co. Ltd., Tokyo, Japan) was used to determine the soluble solids (Raganna, 1979; Tateo, 1979) separately in both caps and stipes. Quadruplicate measurements were made taking portions from at least four mushrooms per flush and extracting the juice by means of a domestic garlic press (Laifa, S.A., Montornés del Vallés, Barcelona, Spain). The final soluble solid content was obtained by considering an 80% contribution from the cap and 20% from the stipe. The results are expressed in °Brix.

To determine the ash content of the carpophores (MAPA, 1994), the samples were incinerated at 540 °C in an electric muffle oven (Selecta, Model Select-Horn; J.P. Selecta, S.A., Abrera, Barcelona, Spain). The results are expressed in g·kg⁻¹.

The pH of the mushrooms was determined directly in the mushroom caps using a penetration electrode (Xerolit, Cat. No. 52-32; Crison Instruments, S.A., Alella, Barcelona, Spain) coupled to a Crison micro pH 2001 pH meter.

Statistical analysis. Quantitative and qualitative parameters were analyzed using the SPSS/PC⁺ 4.0 statistical program of Micromouse S.A. (Madrid, Spain) composed of the base module and Statistics module Version 4.01. The significance of differences between means was determined by analysis of variance using a Tukey's test. Linear correlations were established using a least squares fitting program.

Results and Discussion

Yield and production parameters. The highest number of mushrooms was obtained when Blancochamp BL-40 was used in conjunction with the La Rioja casing material (Table 1), which was also responsible for the highest number of Gurelan 45 mushrooms, although in this case, there were no statistical differences from the results obtained with the mixture of soil and black peat. Regarding Pla 8.9, the greatest number of mushrooms was obtained with the mixture of soil and black peat, differences only being significant with respect to the number obtained with soil alone. The casing of soil without additive, indeed, was the least productive with all three strains evaluated, although only in the case of Blancochamp BL-40 were the differences significant with respect to the other three casing materials, only being different from the mixture of soil and black peat in the case of Pla 8.9, and from the La Rioja material in the case of Gurelan 45.

Regarding total production, the best yields were obtained with Blancochamp BL-40, regardless of the type of casing used, the only combination reaching values anywhere near this (and therefore showing no significant differences) being Gurelan 45 with La Rioja-type material. This material also produced a low percentage of large mushrooms, indicating that it is the best used when mushrooms are destined for canning, whereas, regardless of the yields produced, those mushrooms grown in soil without additives, should be eaten fresh as a result of their larger size. The other casings produced mushrooms of an intermediate size.

The mushrooms of greatest unitary weight for all three strains were obtained with the soil without additives followed by the mixtures of soil with peats. The lowest unitary weights resulted from using the La Rioja-type casing. The importance of size depends on the final destiny of the mushrooms (fresh or preserved), whereas costs, too, are affected because larger mushrooms represent a direct saving in harvesting costs (Schroeder and Schisler, 1981).

The earliest crops were obtained with the La Rioja material, although differences from the soil/brown peat mixture were nonsignificant for any of the strains nor from the soil/black peat mixture used in conjunction with Blancochamp BL-40. The soil with no additives applied to Pla 8.9 was the slowest to fructify, although this combination showed

no significant differences from Gurelan 45 combined with soil alone or mixed with black peat.

Quality parameters. The quality parameters evaluated in the different strains and according to the casing type used are given in Table 2.

The results obtained for L* were similar in all three strains assayed, but only the mushrooms grown with the mixture of soil and black peat showed high values for this parameter. Regarding b*, no significant intra-strain differences were found, suggesting that casing type has no influence on this colorimetric parameter. The best (lowest) value was found for the combination Gurelan 45 and La Rioja-type casing. The ΔE^* values also showed no intrastrain differences, again suggesting that casing plays no role in this parameter. The lowest values once again were observed for the Gurelan 45/La Rioja-type casing combination.

The highest dry matter values were generally obtained in Blancochamp BL-40 followed by Gurelan 45 with no significant differences within one strain. This is a very important parameter from a quality point of view and for mushroom shelf life because high values are correlated with a firm texture, greater nutritive value, and lower susceptibility to microbial deterioration (Beelman, 1988; Schisler, 1983).

When firmness was tested, the mushrooms obtained from Blancochamp BL-40

and Gurelan 45 strains showed higher resistance to penetration than Pla 8.9 mushrooms, a factor which, according to Burton et al. (1995), makes them more acceptable to consumers. Regarding casing material, significant differences were only found for Blancochamp BL-40 with soil alone or mixed with black peat proving the best material in this respect.

The highest protein values were obtained in Blancochamp BL-40 and Pla 8.9 strains. The only significant differences regarding casing material were found in Gurelan 45 between the La Rioja-type material and the mixture of soil and blond peat. All the values obtained are within the range recognized for *A. bisporus* (Pardo, 1999).

The highest soluble solids were obtained with Blancochamp BL-40, especially when soil alone or soil mixed with black peat was used, the differences from the other materials being significant in these two cases.

The highest ash content was provided by Pla 8.9, although the differences between it and Blancochamp BL-40 were not significant when the La Rioja casing was used as was the case with Gurelan 45 for both the La Rioja casing and soil alone. Regarding the casing material effect, significant differences were only found between soil with no additives and La Rioja type in combination with the Blancochamp BL-40 strain. All the values were within the range recognized for *A. bisporus* (Pardo, 1999).

Table 1. Production parameters evaluated from the different mushroom strains with respect to the casing type.

Mushroom strain	Casing layer	Number of mushrooms (mushrooms/m ²)	Mushroom yield (kg·m ⁻²)				Mushroom unitary wt (g)	Earliness (days from casing)
			Large size (40 mm or greater)	Medium size (less than 40 mm)	Nonmarketable mushroom	Total yield		
Pla 8.9	S	943 d ²	7.6 ab	9.0 e	0.2 ab	16.8 cd	18.0 a	29.2 a
Pla 8.9	S + SP	1312 bcd	5.5 bc	11.9 bcde	0.2 ab	17.6 bc	13.5 bc	27.1 bcd
Pla 8.9	S + BP	1519 bc	4.9 bcd	13.3 bcd	0.2 ab	18.4 bc	12.3 c	27.6 bc
Pla 8.9	LRCT	1224 cd	3.5 cd	10.5 cde	0.1 ab	14.1 d	11.7 c	25.4 defg
Blancochamp BL-40	S	1136 cd	10.2 a	9.6 de	0.0 ab	19.8 ab	17.6 a	26.6 bcde
Blancochamp BL-40	S + SP	1737 b	7.0 b	14.3 bc	0.2 ab	21.5 a	12.6 c	24.8 efg
Blancochamp BL-40	S + BP	1792 b	5.9 bc	15.0 b	0.0 ab	20.9 a	12.0 c	24.4 fg
Blancochamp BL-40	LRCT	2717 a	2.4 d	19.2 a	0.0 b	21.6 a	8.1 d	23.9 g
Gurelan 45	S	1068 cd	7.8 ab	10.0 de	0.3 a	18.1 bc	17.1 a	28.0 ab
Gurelan 45	S + SP	1158 cd	7.7 ab	9.9 de	0.2 ab	17.8 bc	15.5 ab	27.4 bcd
Gurelan 45	S + SB	1448 bc	5.2 bcd	13.3 bcd	0.1 ab	18.6 bc	13.1 bc	28.1 ab
Gurelan 45	LRCT	1754 b	3.6 cd	15.6 ab	0.1 ab	19.3 abc	11.2 e	26.0 cdef

Casing layer: S = soil; S + SP = soil + *sphagnum* peat (4:1, v/v); S + BP = soil + black peat (4:1, v/v); LRCT = La Rioja casing type.

²Values followed by different letters within a column are significantly different at $P < 0.05$ (Tukey's test).

Table 2. Quality parameters evaluated from the different mushroom strains with respect to the casing type.

Mushroom strain	Casing layer	Color			Dry matter (g·kg ⁻¹)	Firmness (N)	Protein (g·kg ⁻¹)	Soluble solids (°Brix)	Ash (g·kg ⁻¹)	pH
		L*	b*	ΔE^*						
Pla 8.9	S	93.7 abcd ²	9.8 ab	10.5 abc	79.6 bcd	17.2 def	229.9 bcd	5.3 bc	126.6 a	6.8 bcd
Pla 8.9	S + SP	93.7 abcd	9.6 ab	10.4 abc	77.2 cd	15.8 f	253.1 ab	5.1 bc	127.1 a	6.9 abc
Pla 8.9	S + BP	94.6 a	8.9 abc	9.3 cd	76.8 cd	16.3 ef	240.5 abc	5.3 bc	125.3 ab	6.8 bcd
Pla 8.9	LRCT	93.6 bcd	9.3 abc	10.1 abcd	74.5 d	15.6 f	226.3 bcd	4.7 c	125.1 ab	6.9 abc
Blancochamp BL-40	S	93.5 bcd	9.6 ab	10.5 abc	89.0 a	22.5 a	252.0 ab	6.1 a	103.6 d	6.7 cd
Blancochamp BL-40	S + SP	93.2 cd	9.6 ab	10.6 ab	83.3 abc	20.3 bc	261.9 a	5.3 bc	112.0 cd	6.8 bcd
Blancochamp BL-40	S + BP	93.9 abcd	9.4 ab	10.1 abcd	89.1 a	21.8 ab	244.3 abc	6.0 a	109.2 cd	6.8 bcd
Blancochamp BL-40	LRCT	93.1 d	9.8 ab	10.8 a	83.9 ab	18.2 de	245.9 abc	5.4 b	117.8 abc	6.8 bcd
Gurelan 45	S	93.1 d	9.0 abc	10.0 abcd	79.8 bcd	20.8 abc	222.3 cd	4.8 bc	117.6 abc	6.9 abc
Gurelan 45	S + SP	93.2 d	8.7 bc	9.8 abcd	79.8 bcd	20.4 abc	235.0 abc	4.7 c	114.2 c	7.0 ab
Gurelan 45	S + BP	94.1 abc	8.8 bc	9.4 bcd	83.6 ab	20.7 abc	220.0 cd	5.3 bc	112.7 cd	6.9 abc
Gurelan 45	LRCT	94.2 ab	8.3 c	9.0 d	80.0 bcd	19.0 cd	206.3 d	4.9 bc	116.2 bc	7.0 ab

Casing layer: S = soil; S + SP = soil + *sphagnum* peat (4:1, v/v); S + BP = soil + black peat (4:1, v/v); LRCT = La Rioja casing type.

²Values followed by different letters within a column are significantly different at $P < 0.05$ (Tukey's test).

Table 3. Correlation coefficients and level of significance between different production and quality parameters evaluated in mushroom strains.

Number of mushrooms	Mushroom wt	Total yield	Earliness	L*	b*	ΔE^*	Dry matter	Firmness	Protein	Soluble solids	Ash	pH	Number of mushrooms
Mushroom weight	-0.8202	0.6661	-0.5964	0.0111	-0.0151	0.0132	0.0942	-0.0556	0.0225	0.0698	-0.0732	-0.2813	Mushroom weight
Total yield	+	-0.2477	0.4969	-0.0737	0.0373	0.0349	0.0760	0.2505	0.0393	0.0703	-0.0926	0.1076	Total yield
Earliness	+++	+++	-0.4673	0.0723	-0.0972	-0.0744	0.2170	0.2600	0.0925	0.2187	-0.2779	-0.3279	Earliness
L*	NS	NS	NS	-0.0154	0.1286	0.0785	-0.1224	0.0390	-0.1570	-0.0898	0.1841	0.2162	L*
b*	NS	NS	NS	+++	-0.5142	-0.7372	-0.1915	-0.1707	-0.3697	0.0849	0.1355	0.0678	b*
ΔE^*	NS	NS	NS	+++	+++	0.9565	0.2487	0.0595	0.4532	0.3352	-0.0118	-0.4931	ΔE^*
Dry matter	NS	NS	NS	+++	+++	+	0.2570	0.0999	0.4795	0.2390	-0.0579	-0.4249	Dry matter
Firmness	NS	NS	NS	NS	NS	NS	+++	0.6958	0.2855	0.7873	-0.6545	-0.3957	Firmness
Protein	NS	NS	NS	+++	+++	+++	+++	NS	0.0149	0.4887	-0.7526	-0.1543	Protein
Soluble solids	NS	NS	NS	NS	+++	+	+++	+++	+	0.3014	0.0695	-0.3094	Soluble solids
Ash	NS	NS	NS	NS	NS	NS	+++	+++	NS	+++	-0.4696	-0.5719	Ash
pH	NS	NS	+	NS	+++	+++	+++	NS	NS	+++	+	0.2370	pH

+, ++, +++Significantly different at the 0.05, 0.01, and 0.001 levels, respectively; NS = nonsignificantly different.

No significant differences in the pH of the mushrooms were found for any of the combinations (Table 2), all values being close to neutrality and within the range recognized as normal for *A. bisporus* (Pardo, 1999).

Correlation matrix. The correlation coefficients and level of significance for the different parameters analyzed are given in Table 3.

The negative correlations between the number of mushrooms and unitary weight (-0.820) and earliness (-0.596) and positive correlation with total production (0.666) are worth attention, which indicate that the higher the number of mushrooms harvested per square meter, the greater the total production, the earlier the appearance of the first flush, and the lower the unitary weight. The relation of mushroom numbers and size has also been described by Schisler (1983), according to whom mushroom size and weight depend primarily on the number of primordia that develop at the same time, hence the importance of casing material in which the mushrooms fructify and develop. As a general rule, the more mushrooms that fructify and grow, the more uniform size they will be, although they will also tend to be smaller (Flegg, 1981; Schisler, 1983). The number of mushrooms was also correlated negatively, although at a lower level of significance, with their pH (-0.281).

The unitary weight of the mushrooms was correlated positively with earliness (0.497) and, at a lower level of significance, with total production (-0.248) and firmness (0.251).

Delay in the appearance of the first flush was negatively correlated with total production (-0.467). In this sense, too, Kalberer (1990) noted how reductions in total production were accompanied by slower development. At a lower significance level, total mushroom production was also correlated with dry weight (0.217), firmness (0.260), soluble solids content (0.219), ash (-0.278), and pH (-0.328). Kalberer (1995) noted that a higher dry matter content was always accompanied by lower yields.

L* was negatively correlated with b* (-0.514), ΔE^* (-0.737), and the protein content of mushrooms (-0.370). The yellow-blue component (b*) was also correlated with ΔE^* and the protein content although positively (0.957 and 0.453, respectively) with soluble solids (0.335) and negatively so with pH (-0.493). Greater yellowness (a negative aspect) was therefore correlated with a higher protein and soluble solids content, a positive aspect from a nutritional point of view. ΔE^* was correlated positively with protein content (0.480) and negatively with pH (-0.425).

Dry matter was correlated positively with firmness (0.696), protein content (0.286), and soluble solids (0.787), but negatively with the ash content (-0.655) and pH (-0.396). Gormley (1969) and Schisler (1983), separately, observed how mushrooms with a higher dry matter content had a firmer texture, whereas Kalberer (1990) found a positive correlation between dry matter and the con-

centration of osmotically active substances in mushrooms.

Finally, there were also significant correlations between firmness and soluble solids (0.489) and ash content (-0.753); the protein content and soluble solids (0.301) and pH (-0.310); and between soluble solids and the ash content (-0.470) and pH (-0.572).

Conclusion

The quality and production parameters of three commercial strains of *A. bisporus* growing under different casing mixtures were evaluated. Blancochamp BL-40 produced the greatest number of mushrooms in all the casing mixtures used with high protein, dry matter, and soluble solid contents. Pla 8.9 produced in general a significantly lower yield but with high-quality mushrooms, because the values of protein, soluble solid, and ash content were high. According to casing mixtures used, the Rioja type produced the highest number of mushrooms, although they were smaller and harvested earlier, being appropriate for the preserve industry. When soil without additives was used as a casing layer, mushrooms were larger with a higher dry matter content, firmer, and with a higher content of soluble solids. The mushrooms grown using the soil without additives as a casing layer are preferable for fresh consumption as a result of their larger size.

The correlation matrix showed that a higher number of mushrooms were correlated with a greater overall yield, smaller individual size of mushrooms, and earlier harvesting of first flush. With regard to quality parameters of mushroom, higher values of dry matter content were correlated with firmer textures, greater values of soluble solids and protein contents, and lower values of pH and ash content.

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