A Reliable Quality Index for Mushroom Cultivation

Diego Cunha Zied (Corresponding author)
Departamento de Produção Vegetal, Universidade Estadual Paulista
Fazenda Lageado, PO box 237, CEP 18603-970, Botucatu, SP, Brazil
Tel: 55-14-3811-7167 E-mail: dczied@gmail.com

J. Emilio Pardo-González
Escuela Técnica Superior de Ingenieros Agrónomos, Universidad de Castilla-La Mancha
Campus Universitario, s/n, 02071 Albacete, Spain
E-mail: Jose.PGonzalez@uclm.es

Marli Teixeira Almeida Minhoni
Departamento de Produção Vegetal, Universidade Estadual Paulista
Fazenda Lageado, PO box 237, CEP 18603-970, Botucatu, SP, Brazil
E-mail: marliminhoni@fca.unesp.br

Arturo Pardo-Giménez
Centro de Investigación, Experimentación y Servicios del Champiñón (CIES)
PO box 63, 16220 Quintanar del Rey, Cuenca, Spain
E-mail: apardo.cies@dipucuenca.es

Received: February 9, 2011 Accepted: February 23, 2011 Published: December 1, 2011
doi:10.5539/jas.v3n4p50 URL: http://dx.doi.org/10.5539/jas.v3n4p50

The research was financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES – No. 1184/09-1), the Graduate Program (Energia na Agricultura) in Faculdade de Ciências Agronômicas (FCA/UNESP, Brazil), the Consejería de Agricultura de Castilla-La Mancha (Spain) and the Diputación Provincial de Cuenca (Spain)

Abstract

The aim of this study was to develop a systematic quality index for application in the cultivation of *Agaricus bisporus* (Lange) Imbach mushrooms, based on the physical, chemical and biological properties (indicators) of the compost and casing layers (factors). The relative importance (weight) of each of the factors and indicators, their normalized scores, the quality index values and the correlation with the mushroom yield were evaluated. Three casings (soil + peat moss, Dutch commercial casing, and peat moss + spent mushroom substrate) and two composts were used. The resulting quality index is reliable and useful for identifying problems and can also serve as a rapid tool for possible intervention when problems occur. There was little difference between the two composts used, both of them showing high factor index values. Although the peat + spent mushroom casing presented certain limitations because of its high electrical conductivity, the other two casings showed satisfactory factor index values.

Keywords: Methodological interactions, Yield modeling, Worldwide databases, Mushroom technology

1. Introduction

The methodology used to obtain a "quality index" has been applied in agricultural research, especially in the field of soil science (Glover et al., 2000; Doran and Park in, 1994). For example, according to Larson and Pierce

(1994), soil quality is a combination of the physical, chemical and biological properties of soil as well as its capacity to promote the growth of vegetables and animals, to regulate the flow of water in the environment and to act as a filter in the degradation and degeneration of environmentally hazardous substances.

However, quality index methodology has never been applied to mushroom production. Here, were study *Agaricus bisporus* (Lange) Imbach, the most widely cultivated mushroom in the world, for which an abundant literature exists concerning appropriate cultivation technology, especially optimal growth conditions and the factors that affect yield. In this work, were focus on the compost and casing layer.

The development of a quality index for mushroom cultivation is important in that it can help identify problems in the cultivation process, provide realistic yield estimates and avoid potential errors, while enabling government sectors to monitor the sustainability and quality of mushroom production and the changes related with the compost and casing layers used.

Sustainability in mushroom production is a multi-dimensional concept that includes aspects such as the stability of production and profit, the protection and improvement of basic natural resources (biotic and abiotic) and the maintenance of social order (e.g., the maintenance of family farms and industry).

Based on the different aspects and stages of *A. bisporus* production, four basic steps must be followed for precise quality evaluation and monitoring: 1) select and define the principal factor (or factors) involved in the commercial production of mushrooms that need to be assessed (e.g., compost and/or casing); 2) establish the attributes that are relevant to the quality indicators for the selected factors (e.g., “pH and C/N ratio” for compost); 3) determine the key points of data analysis and specify the evaluation and integration process (analysis method, weight (a and b) and slope at baseline); 4) establish specific criteria for the interpretation of the data to guarantee reliable estimates of the production quality of each attribute (e.g., normalized score).

To be of practical use to professionals (researchers, extension agents, growers, designers and others), quality indicators must meet the following criteria: a) be accessible to users worldwide and facilitate measurement; b) be applicable to any growth condition; c) own criteria for quantification and interpretation of values; d) be flexible in the face of changes (variations in temperature, humidity and CO_2, irrigation alterations that cause problems with casing layer compaction, etc.); e) allow both short- and long-term assessments of production quality; f) if possible, be components of existing databases.

Based on the above mentioned criteria, compost and casing layers were selected from the many factors involved in mushroom cultivation to be the key factors in our analyses. The following parameters were evaluated and integrated:

- Indicators of compost quality: moisture content, C/N ratio, pH, nitrogen and presence of mites, nematodes and competitor moulds.

- Indicators of casing layer quality: water-holding capacity, porosity, pH, electrical conductivity and presence of mites, nematodes and competitor moulds.

Two compost and three casing layers were used in our study. The aim was to develop a systematic quality index of the physical, chemical and biological properties (indicators) of the compost and casing layers (factors). The relative importance (weight) for each of the factors and indicators, their normalized scores, the quality index values and the correlation with the mushroom yield at the end of the harvest period were also evaluated.

2. Materials and methods

The experiment was carried out at the Centro de Investigación, Experimentación y Servicios del Champiñón (CIES), Quintanar del Rey (Cuenca, Spain) in a controlled room used specifically for mushroom growing. The total research time was 52 days (14 days of spawn run and 38 days of harvest phase).

2.1 Mushroom strain

The commercial strain “Gurelan 45” (large off-white hybrid) was used. The spawn is recommended for cultivation in the winter and spring, and the optimal fruiting conditions are 18ºC (although it may bear fruit at 15ºC), a relative humidity of 87% and adequate ventilation to keep CO_2 levels between 1000 and 1500 ppm.

2.2 Composts

Two commercial composts from different composting facilities were used. For both composts, Phase I was carried out in bunkers with controlled air flow, and Phase II in a pasteurization tunnel to eliminate pests and diseases. The physical, chemical and biological properties of these composts are summarized in Tables 2, 3 and 4.

2.3 Casing layers

Three casing layers were used in this study: soil + peat moss "brown peat" (4:1, v/v), Dutch commercial casing (DCC) and peat moss "brown peat" + spent mushroom substrate (SMS) (3:2, v/v). Their physical, chemical and biological properties are presented in Tables 2, 3 and 4, respectively.

2.4 Growing of mushrooms

After applying the casing layer over the composts, the plastic boxes were transferred to the production chamber where disinfectant treatment (formalin, 18 ml m^{-2}), insecticide treatment (diflubenzuron 25%, 3.6 g m^{-2}) and fungicide treatment (prochloraz 46%, 0.62 g m^{-2}) were done on days 1, 3 and 5, respectively. The casing was deeply raked on day 6, and ventilation was carried out 11 d after casing to stimulate primordia formation. The growth cycle after casing lasted 38 d, and three flushes of mushrooms were harvested.

2.5 Quality index

Were assessed the quality indexes for the two composts and three casing layers in the cultivation of *A. bisporus*.

2.5.1 Factors to evaluate

Any proposals to improve or increase *A. bisporus* yield necessarily involves through two stages of the production process: composting and the selection and preparation of the casing layer.

As regards composts, the different factors that should be considered include changes in raw materials or supplements, the methods used in composting (Phase I and Phase II), the formulations used, and all the other aspects that can directly affect the physical, chemical and biological properties of the composts. For this reason, two different composts from two commercial facilities, each prepared with a particular method, formulation and technique, were selected.

Three casing materials were selected for the same reason. These included two organic casings (Dutch commercial casing as a reference, and peat moss + SMS, considered an interesting alternative for growers that reuse spent mushroom compost) and soil + peat moss (widely used worldwide), a mixture with high mineral soil content.

2.5.2 Quality indicators

To establish the best quality indicators for the compost and casing layers that directly affect the yield of mushrooms, were selected the following principal parameters, which can be analyzed by well-defined analytical methods at low cost.

- Compost: moisture (Mapa, 1994), pH (Ansorena, 1994; Aenor, 2001a), total N content (Mapa, 1994; Tecator, 1987), C/N ratio (calculated from the total nitrogen and the total organic matter), and the presence of mites (Brady, 1969; Krantz, 1986), nematodes (Nombela and Bello, 1983) and competitor moulds (Tello et al., 1991).

- Casing layer: water holding capacity (Ansorena, 1994; Aenor, 2001c), porosity (Ansorena, 1994; Aenor, 2001c), pH (Ansorena, 1994; Aenor, 2001a), electrical conductivity (Aenor, 2001b), and the presence of mites (Brady, 1969; Krantz, 1986), nematodes (Nombela and Bello, 1983) and competitor moulds (Tello et al., 1991).

2.5.3 Critical limits for quality indicators

Based on previous data (Gerrits, 1988; Visscher, 1988; Pardo, 1994; Hearne, 1994; Pardo, 1999; Shekhar Sharma and Kilpatrick, 2000), the laboratory records at the Centro de Investigación, Experimentación y Servicios del Champiñón and the practical experience of the author and their collaborators in experimental and industrial cultivation, the critical limits and the optimal values of the indicators were defined, as shown in Table 1.

2.5.4 Weights for each factor (a) and for each quality indicator (b)

Based on their relative importance for yield, the compost factor was given a weight of 0.65 and the casing layer factor a weight of 0.35 (the numerical weights must total 1.0). We also established the weights of the quality indicators (their sum must also be 1). The most influential indicator for the final behavior of the crop was selected according to its importance and the possible consequences due to deviations from optimal values.

For example, in addition to being a key element in "Phase I and II" of the composting process, the total N content of the compost is directly linked to other factors that may affect yield. A high N content would favor the presence of contaminants such as *Coprinus* and *Chaetomium* in the compost; moreover, if poorly composted, NH_3 becomes toxic to the mushrooms, while a low N content would cause problems with fermentation during Phase I (difficult for the temperature to reach 75-80ºC) lower yield and longer mean spawn-run time, which, jointly, mean a higher risk of compost contamination and a longer growing cycle.

The weight was set for each factor and quality indicator, as shown in Table I. For the different factors, the numerical weights assigned to all the quality indicators must add up to 1.0 at each level.

2.5.5 Normalized scores obtained (c) for the indicators

The normalized score of the indicators ranged from 0 to 1.0, with 0 representing the worst value and 1 representing the best value. The scoring curves were generated using the following equation (1) (Wymore, 1993):

$$\upsilon = \frac{1}{1+\left[(B-L)/(X-L)\right]^{2S(B+x-2L)}} \tag{1}$$

where υ is the normalized score, B is the critical value or the baseline value of the indicator (a score of 0.5 sets the difference between a bad and good quality indicator), L is the initial value, which can be lower than a property and can be expressed as 0, S is the slope of the tangent to the curve at the critical value of the indicator and x is the indicator value measured in the laboratory.

To apply the above-mentioned equation of Wymore (1993), the slope (S) of the tangent to the curve at the critical value of the indicator (υ = 0.5) was first calculated using the following equation (2):

$$S = \frac{\log\left(\frac{1}{\upsilon}-1\right)}{2(B+x-2L)\log\left(\frac{B-L}{x-L}\right)} \tag{2}$$

With the scoring curve equations, three types of normalized scoring functions were generated (Figure 1): (a) "More is better", e.g., water holding capacity and porosity; (b) "Less is better", e.g., electrical conductivity and the presence of mites; (c) "Optimum", e.g., pH and C/N ratio.

2.5.6 Calculation of final quality index

The quality index (Q) for the cultivation of *A. bisporus* was obtained in two stages. The indexes of each individual factor were first calculated (1st step), and their sum provided the factor index for each compost-casing combination (2nd step):

$$\left.\begin{aligned} Q_1 &= a_1\sum_{i=1}^{m}(b_i c_i) \\ Q_2 &= a_2\sum_{j=1}^{n}(b_j c_j) \end{aligned}\right\} \quad (1^{st}\ \text{step}).$$

$$Q = Q_1 + Q_2 \qquad (2^{nd}\ \text{step}).$$

where Q_1 and Q_2 are the index values of the main factors (compost and casing layer), a_1 and a_2 are the weights of these factors, b_i and b_j are the weights of the *m* indicators of factor 1 (compost) and the *n* indicators of factor 2 (casing layer), c_i and c_j are the normalized scores of these indicators. *Q* is the final quality index value.

2.6 Test of the feasibility of modeling

To verify the safety and significance of this methodology, a correlation analysis was carried out for the final quality index values obtained for the six compost-casing combinations and the yield values recorded at the end of the growing for the same combinations. SigmaStat 3.5 with the Linear Regression tool was used for data analysis.

3. Results and discussion

Tables 2, 3 and 4 summarize the quality indexes obtained for each different casing layer, which include the main factors, the indicators within each factor, the weights of each factor (^{a}) and indicator (^{b}), the mean observed values, the normalized scores of each indicator (^{c}), the factor index and the calculated values of the quality indexes.

The data were grouped according to the casing layers, with each table showing the values obtained for one type of casing layer cultivated with two different composts. The same method was previously used by Karlen and Stott (1994) to define a soil quality index. These authors stated that if the observed values of the indicators were equal to their critical limits, the quality index would be equal to 0.5. Values below 0.5 would represent soils with more limitations, and values above 0.5 soils with fewer limitations.

Thus, the maximum possible value for any normalized score (^{c}) or factor-quality index is 1.0. The closer the value is to 1.0, the better the result selected for each evaluation.

Analyses of both the compost and the casing layers showed that all the quality index values were above the critical limit (0.5), and arranged in the following descending order: Compost1/DCC (0.993) > Compost2/DCC (0.990) > Compost1/Soil + peat (0.978) > Compost2/Soil + peat (0.975) > Compost1/peat + SMS (0.953) > Compost2/peat + SMS (0.950).

It follows that compost 1 has a better factor index value than compost 2, and, as regards the casing layers, DCC has the highest factor index value and peat + SMS (3:2, v/v) the lowest.

It is important to emphasize that this method can be used worldwide to study quality indexes for the cultivation of *A. bisporus*. A database with different types of compost and casing layers used in both situations (past and present) can be built, which will give realistic estimates of the quality indexes expected for each country.

A further examination of the data revealed little differences in the compost index values (0.995 and 0.992 for compost 1 and 2, respectively). The lowest normalized score (^{c}) of 0.984 was obtained for pH in compost 2, which can still be considered a high value indicating good quality.

Based on the observed results, we conclude that the composting process was well established and developed in these two facilities, and that the substrates were well suited for our research, especially with regard to their physical, chemical and biological characteristics.

For fungiculture practice, it would be of great interest to periodically sample all existing composting facilities to identify potential problems (such as technical errors in the process, limitations of the constructions and bad materials used) and provide suggestions at critical time points.

Unlike the results obtained for the composts, substantial differences were found between the casing layers, with the factor index values ranging from 0.989 (DCC, Table 3) to 0.876 (peat + SMS, Table 4). Possible actions to improve the quality indicator valued below 1.0 in the peat + SMS casing would include correcting the value of the electrical conductivity (with a normalized score (^{c}) of 0.183), increasing the leaching of the SMS by adding more water and extending the maturation period. Another alternative strategy would be to mix small amounts of SMS with peat moss, black peat or mineral soil for use as casing layer.

Rendering to the yield obtained at the end of the harvest phase, this methodology showed high correlation coefficient (R=0.829) between the yields and quality index values (Figure 2) and is therefore reliable.

According to van Griensven (1982), Flegg (1985), Oei (2003) Zied et al. (2010) and Pardo et al. (2010), the yield values of this work (ranging from 31.0 to 37.1%) were within the range considered satisfactory (25-40%) for *A. bisporus* cultivation, and can be ordered in the following decreasing order: compost1/DCC (37.1%) > Compost2/DCC (35.9%) > Compost1/Soil + peat (34.7%) > Compost2/peat + SMS (32.1%) > Compost2/Soil + peat (31.1%) > Compost1/peat + SMS (31.0%).

It should be noted that the factors and indicators proposed in this paper and their critical limits and weights may not necessarily be fixed. Due to the flexibility of the factor selection process, additional indicators can always be included for better adaption to local conditions. Logically, they can also include other factors of production such as the grower's knowledge (training and experience), characteristics of the facilities (construction aspects and degree of automation) or the mycelium used.

To predict precise quality index values, more work needs to be done, and more indexes should be analyzed. With the continuation of our current work (to test other factors-indicators and their respective weights), the proposed quality index method will become more reliable and should eventually become an indispensable tool for mushroom cultivation (*A. bisporus* and others) worldwide.

4. Conclusions

This methodology used to obtain the quality index analysis is reliable and practical for identifying problems and can also serve as a rapid tool for possible intervention when problems occur. There was little difference between the two composts, both of which showed high factor index values. Although the peat + SMS based casing layer presented certain limitations as a result of its high electrical conductivity, the other two casings showed satisfactory factor index values.

References

Aenor. (2001a). *Mejoradores de suelos y sustratos de cultivo. Determinación del pH*, ed. Asociación Española de Normalización y Certificación (AENOR) - Norma Española UNE-EN 13037, Madrid.

Aenor. (2001b). *Mejoradores de suelos y sustratos de cultivo. Determinación de la conductividad eléctrica*. ed. Asociación Española de Normalización y Certificación (AENOR) - Norma Española UNE-EN 13038, Madrid.

Aenor. (2001c). *Mejoradores de suelos y sustratos de cultivo. Determinación de las propiedades físicas. Densidad aparente seca, volumen de aire, volumen de agua, valor de contracción y porosidad total*. ed. Asociación Española de Normalización y Certificación (AENOR) - Norma Española UNE-EN 13041, Madrid.

Ansorena, J. (1994). *Sustratos. Propiedades y caracterización*, ed. Mundi-Prensa S.A., Madrid.

Brady, J. (1969). Some physical gradients set up in Tullgren funnels during the extraction of mites from poultry litter. *Journal of Applied Ecology*, 6, 391-402. http://dx.doi.org/10.2307/2401506

Carter, M.R. (2002). Quality, critical limits and standardization. in: Lal, R. (Eds.) *Encyclopedia of soil science*. New York, pp. 1062-1065.

Doran, J.W., & Parkin, T.B. (1994). Dedining and assessing soil quality. In Doran, J.W., Coleman, D.C., Bezdicek, D.F., & Stewart, B.A. (Eds.) *Defening Soil Quality for a Sustainable Environment* (pp. 3-21). SSSA Special Pub. 35, Madison.

Flegg, P.B., Spencer, D.M., & Wood, D.A. (1985). *The Biology and Technology of the Cultivated Mushroom*, John Wiley and Sons, Chichester.

Gerrits, J.P.G. (1988). Nutrition and Compost. in: van Griensven (Eds.) *The Cultivation of Mushrooms* (pp. 29-72). Sussex.

Glover, J.D., Reganold, J.P., & Andrews, P.K. (2000). Systematic method for rating soil quality of convetional, organic, and integrated apple orchards in Washington State. *Agriculture, Ecosystems & Environment*, 80, 29-45. http://dx.doi.org/10.1016/S0167-8809(00)00131-6

Hearne, A.J. (1994). Mushroom compost analysis. A few practical suggestions. *Mushroom Journal*, 539, 18-19.

Krantz, G.W. (1986). *A manual of acarology*, second ed. Oregon State University Book Stores, Corvallis.

Karlen, D.L., & Stott, D.E. (1994). A framework for evaluating physical and chemical indicators of soil quality. in: Doran, J.W., Coleman, D.C., Bezdicek, D.F., & Stewart, B.A. (Eds.) *Defening Soil Quality for a Sustainable Environment* (pp. 53-72). SSSA Special Pub. 35, Madison.

Larson, W.E., & Pierce, F.J. (1994). The dynamics of soil quality as a measure of sustainable management. in: Doran, J.W., Coleman, D.C., Bezdicek, D.F., & Stewart, B.A. (Eds.) *Defening Soil Quality for a Sustainable Environment* (pp. 37-52). SSSA Special Pub. 35, Madison.

Mapa. (1994). *Métodos Oficiales de Análisis*, ed. Ministerio de Agricultura, Pesca y Alimentación, Madrid.

Nombela, G. & Bello, A. (1983). Modificaciones al método de extracción de nematodos fitoparásitos por centrifugación en azúcar. *Boletín de Sanidad Vegetal-Plagas*, 9, 183-189.

Oei, P. (2003). *Mushroom cultivation*, third ed. Backhuys Publishers, Leiden.

Pardo, J. (1994). Productividad de un compost y economía de su elaboración: criterios de evaluación basados en una analítica sistemática. in: Consejería de Agricultura y Medio Ambiente y Diputación Provincial de Cuenca (Eds.) *Jornadas Técnicas del Champiñón y otros Hongos Comestibles en Castilla-La Mancha* (pp. 37-58). Cuenca.

Pardo, A. (1999). *Respuestas agronómicas de diferentes materiales de cobertura para el cultivo del champiñón, Agaricus bisporus (Lange) Imbach*. Dissertation, Universidad de Castilla-La Mancha.

Shekhar Sharma, H.S., & Kilpatrick, M. (2000). Mushroom (*Agaricus bisporus*) compost quality factors for predicting potential yield of fruiting bodies. *Canadian Journal of Microbiology*, 46, 515-519.

Tecator. (1987). *Determination of Kjeldahl nitrogen content with the kjeltec Auto 1030 Analyzer*, Tecator Application Note 30/87, Hönagäs.

Tello, J., Varés, F., & Lacasa, A. (1991). Selección y tratamiento de muestras. Análisis de muestras. Observación microscópica. in: Ministerio de Agricultura, Pesca y Alimentación, Dirección General de Sanidad de la Producción Agraria Manual de laboratorio (Eds.) *Diagnóstico de hongos, bacterias y nematodos fitopatógenos* (pp. 29-77). Madrid.

van Griensven, L.J.L.D. (1988). *The cultivation of mushrooms*, Mushroom Experimental Station, Horst.

Visscher, H.R. (1988). Casing soil. in: van Griensven (Eds.) *The Cultivation of Mushrooms* (pp. 73-89). Sussex.

Wymore, A.W. (1993). *Model-Based Systems Engineering.* An Introduction to the Mathematical Theory of Discrete Systems and to the Tricotyledon Theory of System Design, CRC, Boca

Table 1. Compost and casing layer quality score card for the integrated management treatment

Factor	Weight(a)	Quality Indicator[3]	Scoring curve[4]	Weight(b)	Critical Limits		Optimum
					Lower	Upper	
Compost (Phase II)[1]	0,65	Moisture	Optimum	0.25	60	75	67
		C/N ratio	Optimum	0.30	16	22	19
		pH	Optimum	0.18	7	8	7.4
		Total nitrogen	Optimum	0.16	1.7	2.6	2.2
		Mites	Less is better	0.05	10	-	-
		Nematodes	Less is better	0.03	10	-	-
		Competitor moulds	Less is better	0.03	Absence	-	-
Casing layer[2]	0,35	Water holding capacity	More is better	0.28	45	-	-
		Porosity	More is better	0.28	50	-	-
		pH	Optimum	0.19	6.8	9	7.8
		Electrical conductivity	Less is better	0.14	1600	-	-
		Mites	Less is better	0.05	10	-	-
		Nematodes	Less is better	0.03	10	-	-
		Competitor moulds	Less is better	0.03	Absence	-	-

[1]Compost (Phase II) = analysis done in the compost at the end of the pasteurization process for its physical, chemical and biological conditions.

[2]Casing layer = analysis done in the casing layer before the addition of colonized compost.

[3]Indicators: Moisture, %; C/N ratio; pH; Total N content, %; Mites, individuals/100 g compost; nematodes, individuals/100 g compost; Competitor moulds: the presence or absence; Water holding capacity, % and Porosity, %.

[4]Optimum: Type curve of normalized scores "optimum"; Type curve of normalized scores "less is better" and Type curve of normalized scores "more is better".

([a]) Function level weight scores are the sums of associated Level 1 indicator values.

([b]) For Level 1 indicators that are determined by Level 2 indicators (i.e., moisture), the weight scores are the sums of Level 2 indicator values.

Table 2. Weight (a and b) of factor and indicators, normalized score (c) and final quality index values for evaluating soil + peat moss (4:1, v/v) casing

Compost	Factor	Weight (a)	Quality Indicator	Weight (b)	Critical Limits Lower	Critical Limits Upper	Optimum	Observed value	Slope at baseline	Normalized Score (c)	(b) x (c)	Sum (b) x (c) (d)	Factor index (d) x (a)	Quality Index Value*
			Moisture	0.25	60	75	67	66	0.25025	0.997	0.249			
			C/N ratio	0.30	16	22	19	19.2	0.41708	0.99	0.297			
			pH	0.18	7	8	7.4	7.5	3.03333	0.997	0.179			
	Compost (Phase II)	0.65	Total N	0.16	1.7	2.6	2.2	2.2	-	1	0.16	0.995	0.647	
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
1			Water holding capacity	0.28	45	-	-	66.9	0.03544	0.958	0.249			0.978
			Porosity	0.28	50	-	-	71.9	0.02176	0.872	0.297			
			pH	0.19	6.8	9	7.8	7.5	2.00200	0.996	0.179			
	Casing Layer	0.35	Electrical conductivity	0.14	1600	-	-	235	-0.0005	0.971	0.16	0.947	0.331	
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
			Moisture	0.25	60	75	67	68.10	0.25025	0.999	0.249			
			C/N ratio	0.30	16	22	19	19.40	0.41708	0.987	0.296			
			pH	0.18	7	8	7.4	7.66	3.03333	0.984	0.177			
	Compost (Phase II)	0.65	Total N	0.16	1.7	2.6	2.2	2.26	3.85005	0.994	0.159	0.992	0.644	
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
2			Water holding capacity	0.28	45	-	-	66.9	0.03544	0.958	0.249			0.975
			Porosity	0.28	50	-	-	71.9	0.02176	0.872	0.297			
			pH	0.19	6.8	9	7.8	7.5	2.00200	0.996	0.179			
	Casing Layer	0.35	Electrical conductivity	0.14	1600	-	-	235	-0.0005	0.971	0.16	0.947	0.331	
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			

(a) Function level weight scores are the sums of associated Level 1 indicator values.

(b) For Level 1 indicators that are determined by Level 2 indicators (i.e., moisture), the weight scores are the sums of Level 2 indicator values.

Table 3. Weight ([a] and [b]) of factor and indicators, normalized score ([c]) and final quality index values for evaluating DCC (4:1, v/v) casing

Compost	Factor	Weight ([a])	Quality Indicator	Weight ([b])	Critical Limits Lower	Critical Limits Upper	Optimum	Observed value	Slope at baseline	Normalized Score ([c])	([b]) x ([c])	Sum ([b]) x ([c]) ([d])	Factor index ([d]) x ([a])	Quality Index Value*
1	Compost (Phase II)	0.65	Moisture	0.25	60	75	67	66	0.25025	0.997	0.249	0.995	0.647	0.993
			C/N ratio	0.30	16	22	19	19.2	0.41708	0.99	0.297			
			pH	0.18	7	8	7.4	7.5	3.03333	0.997	0.179			
			Total N	0.16	1.7	2.6	2.2	2.2	-	1	0.16			
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
	Casing Layer	0.35	Water holding capacity	0.28	45	-	-	387.6	0.03544	1	0.28	0.989	0.346	
			Porosity	0.28	50	-	-	91.5	0.02176	0.976	0.273			
			pH	0.19	6.8	9	7.8	8.0	2.00200	0.999	0.189			
			Electrical conductivity	0.14	1600	-	-	210	-0.0005	0.975	0.136			
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
2	Compost (Phase II)	0.65	Moisture	0.25	60	75	67	68.10	0.25025	0.999	0.249	0.992	0.644	0.990
			C/N ratio	0.30	16	22	19	19.40	0.41708	0.987	0.296			
			pH	0.18	7	8	7.4	7.66	3.03333	0.984	0.177			
			Total N	0.16	1.7	2.6	2.2	2.26	3.85005	0.994	0.159			
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
	Casing Layer	0.35	Water holding capacity	0.28	45	-	-	387.6	0.03544	1	0.28	0.989	0.346	
			Porosity	0.28	50	-	-	91.5	0.02176	0.976	0.273			
			pH	0.19	6.8	9	7.8	8.0	2.00200	0.999	0.189			
			Electrical conductivity	0.14	1600	-	-	210	-0.0005	0.975	0.136			
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			

([a]) Function level weight scores are the sums of associated Level 1 indicator values.

([b]) For Level 1 indicators that are determined by Level 2 indicators (i.e., moisture), weight scores are the sums of Level 2 indicator values.

Table 4. Weight ([a] and [b]) of factor and indicators, normalized score ([c]) and final quality index values for evaluating brown peat + spent mushroom substrate (2:3, v/v) casing

Compost	Factor	Weight ([a])	Quality Indicator	Weight ([b])	Critical Limits Lower	Critical Limits Upper	Optimum	Observed value	Slope at Baseline	Normalized Score ([c])	([b]) x ([c])	Sum ([b]) x ([c]) ([d])	Factor index ([d]) x ([a])	Quality Index Value*
1	Compost (Fase II)	0.65	Moisture	0.25	60	75	67	66	0.25025	0.997	0.249	0.995	0.647	0.953
			C/N ratio	0.30	16	22	19	19.2	0.41708	0.99	0.297			
			pH	0.18	7	8	7.4	7.5	3.03333	0.997	0.179			
			Total N	0.16	1.7	2.6	2.2	2.2	-	1	0.16			
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
	Casing Layer	0.35	Water holding capacity	0.28	45	-	-	334	0.03544	1	0.28	0.876	0.306	
			Porosity	0.28	50	-	-	88.5	0.02176	0.969	0.271			
			pH	0.19	6.8	9	7.8	7.66	2.00200	0.999	0.189			
			Electrical conductivity	0.14	1600	-	-	2337	-0.0005	0.183	0.025			
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
2	Compost (Fase II)	0.65	Moisture	0.25	60	75	67	68.10	0.25025	0.999	0.249	0.992	0.644	0.950
			C/N ratio	0.30	16	22	19	19.40	0.41708	0.987	0.296			
			pH	0.18	7	8	7.4	7.66	3.03333	0.984	0.177			
			Total N	0.16	1.7	2.6	2.2	2.26	3.85005	0.994	0.159			
			Mites	0.05	Absence	-	-	0	-	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			
	Casing Layer	0.35	Water holding capacity	0.28	45	-	-	334	0.03544	1	0.28	0.876	0.306	
			Porosity	0.28	50	-	-	88.5	0.02176	0.969	0.271			
			pH	0.19	6.8	9	7.8	7.66	2.00200	0.999	0.189			
			Electrical conductivity	0.14	1600	-	-	2337	-0.0005	0.183	0.025			
			Mites	0.05	Absence	-	-	0	-0.1214	1	0.05			
			Nematodes	0.03	Absence	-	-	0	-0.2075	1	0.03			
			Competitor moulds	0.03	Absence	-	-	0	-	1	0.03			

([a]) Function level weight scores are the sums of associated Level 1 indicator values.

([b]) For Level 1 indicators that are determined by Level 2 indicators (i.e., moisture), weight scores are the sums of Level 2 indicator values.

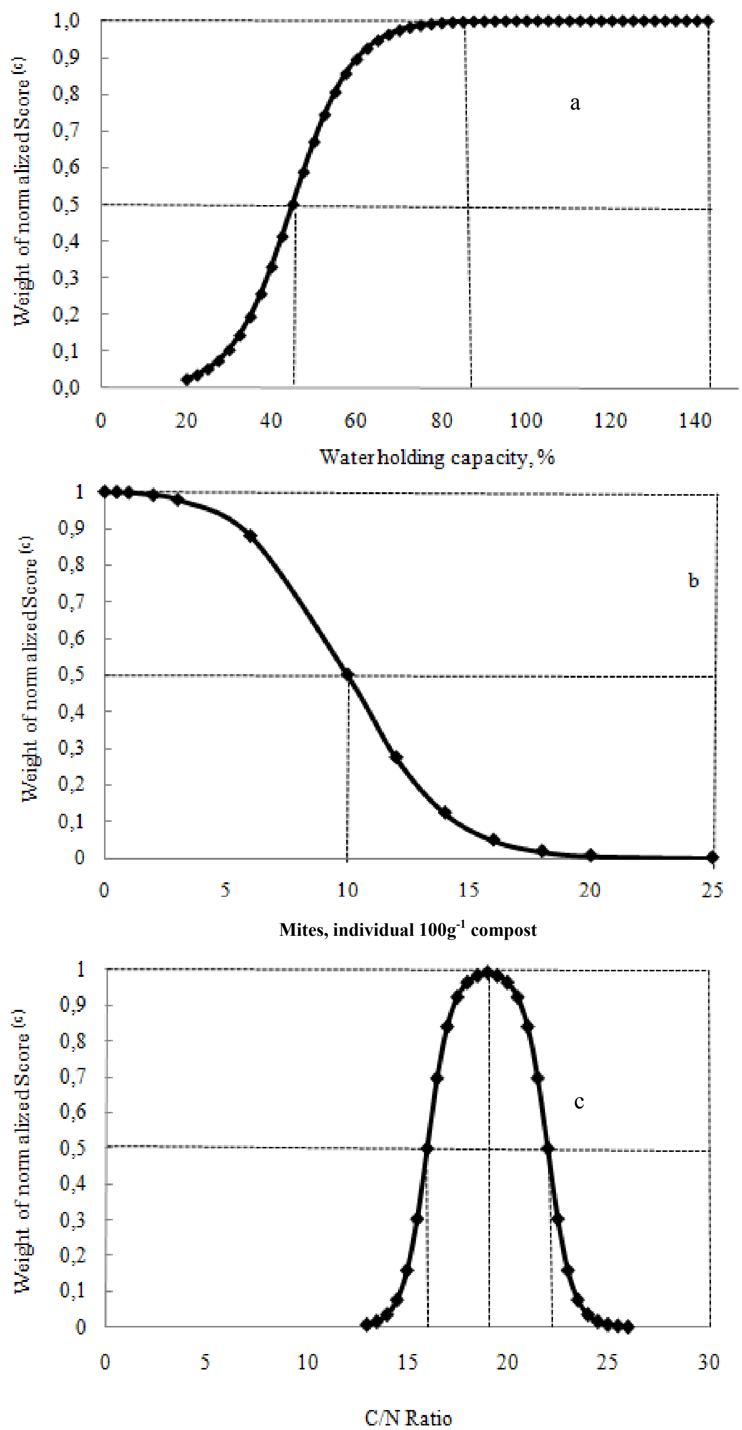

Figure 1. (a) “More is better” normalized score function as applied to water holding capacity. (b) “Less is better” normalized scoring function as applied to the presence of mites. (c) “Optimum” normalized scoring function as applied to C/N ratio

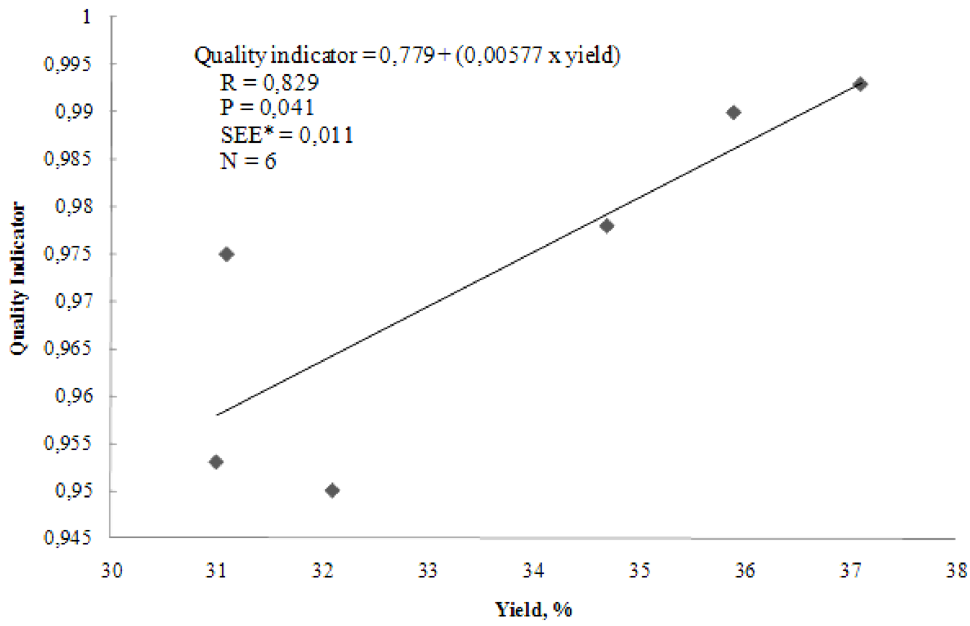

Figure 2. Correlation between the quality index values and the yields of *A. bisporus* obtained for two composts and three casing layers (*SEE = standard error of estimate)