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Influence of cutting direction of cork planks on the quality and porosity characteristics of natural cork stoppers

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Abstract

In the industrial production of natural cork stoppers, cork planks are cut transversely into strips and stoppers are bored in the axial direction, therefore with their cylinder axis parallel to the tree axial direction. The influence of cutting direction of cork planks (transverse or longitudinal), and therefore the orientation of stoppers cylindrical axis (longitudinal or tangential, respectively) on yields, quality profile and porosity characteristics was studied in a random sampling of planks of different quality classes that were bored to produce 45 mm × 24 mm stoppers. The stoppers quality profile and production values were not influenced by the cutting direction, although in good quality planks (1st/2nd) the longitudinal cut led to a higher proportion of good quality stoppers in comparison to the transversal cut, 32% *vs.* 23%. Regarding porosity characteristics, pore orientation differed between the two cutting directions but not the porosity coefficient, with the exception of the poor quality classes.

Key words: cork planks, natural cork stoppers, image analysis, quality evaluation, porosity, cutting direction.

Resumen

Influencia de la dirección de corte de planchas de corcho en la calidad y características de porosidad de tapones de corcho natural

En la producción industrial de tapones de corcho natural las planchas de corcho son cortadas transversalmente en tiras y los tapones son perforados en la dirección axial, por lo que el eje del cilindro del tapón es paralelo a la dirección axial del árbol. En este trabajo se analiza la influencia de la dirección de corte de planchas de corcho (transversal o longitudinal) y, por tanto, de la orientación del eje del cilindro de los tapones de corcho (longitudinal o tangencial respectivamente), en el rendimiento, perfil de calidad y características de porosidad, a partir de una selección aleatoria de planchas de corcho de diferente calidad, de la que se obtuvieron tapones de 45 mm × 24 mm. El perfil de calidad de los tapones y el rendimiento no se vio influenciado por la dirección de corte, aunque en planchas de buena calidad (1.ª/2.ª) el corte longitudinal produjo una proporción más elevada de tapones de buena calidad en comparación con el transversal (32% frente a 23%). Con relación a las características relacionadas con la porosidad, la orientación de los poros fue diferente en las dos direcciones de corte pero no el coeficiente de porosidad, a excepción de las clases inferiores de calidad.

Palabras clave: planchas de corcho, tapones de corcho natural, análisis de imagen, evaluación de la calidad, porosidad, dirección de corte.

Introduction

The industrial processing of cork planks for the manufacture of natural cork stoppers can be described by three sequential phases (Pereira, 2007):

i) Preparation of cork, where the cork planks, after field and mill yard storage for about 6 months, are immersed in boiling water during 1 hour, dried for 2-3 days, trimmed and separated into cork boards by calliper and quality classes;

ii) Production of stoppers, where the graded cork boards are cut transversely into cork strips (called *rabanadas*) with an height corresponding to the stopper's length, the cork strips are bored with cutting cylinders with an inside diameter corresponding to the desired stopper's diameter and the obtained stoppers are dimensionally rectified (tops and the cylindrical body) by sanding;

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iii) Finishing, where the cork stoppers are washed, dried and graded into commercial quality classes (usually into seven classes) and undergo a final surface finishing.

Figure 1 shows a schematic representation of the main operations involved in the industrial production of natural cork stoppers.

In the industrial processing for production of natural cork stoppers two main factors determine its economic feasibility: the yield of production, *i.e.* the efficiency of raw material use and the quality of the obtained stoppers. Cork is a natural raw material with high heterogeneity and therefore production yield and quality diversity are to be expected. The mass production yield of stoppers is on average less than one quarter of the cork planks that are bored (Fortes *et al.,* 2004), whereas the economic return is directly influenced by the quality of the resulting stoppers, *e.g.* the price of a good quality stopper can be five times higher than that of a low quality stopper. The quality profile of stoppers depends on the quality of cork planks, which is grossly assessed visually by thickness, presence/ absence of defects and the extent of the lenticular channel porosity. Good planks yield a larger percentage of stoppers of the best quality classes (Pereira *et al.,* 1994; Beja, 2001).

The quality of raw material and of final product is therefore a key factor in the industrial processing and crucial in establishing the production value. The cork industry has adopted image vision inspection systems for cork stopper quality classification. These high production rate systems are based on a line scan camera and a computer embedded in an industrial sorting machine capable of acquiring and processing in real-time the surface image of the cork stoppers and classifying the stoppers into quality grades. The classification is based on decision-making structures on quantifiable variables on the body surface and tops of the stoppers, such as maximum pore area and porosity coefficient (Costa and Pereira, 2005, 2006, 2007). Good quality stoppers have few and small pores, while poor quality stoppers have many and large pores.

The cork quality is directly related to the porosity derived from the presence of lenticular channels that cross the plank radially, from belly to cork back. Thus, the transverse and radial surfaces of cork show longitudinal sections of the lenticular channels and the tangential surface shows the channels in section. The characteristics of porosity have been well studied: on average the lenticular channels have an approximately circular section elongated along the axial direction of cork, but with a large variability, both in size and orientation (Pereira et *al.,* 1996; Costa and Pereira, 2005).

The production of natural cork stoppers originates a large amount of by-products for the cork agglomerates

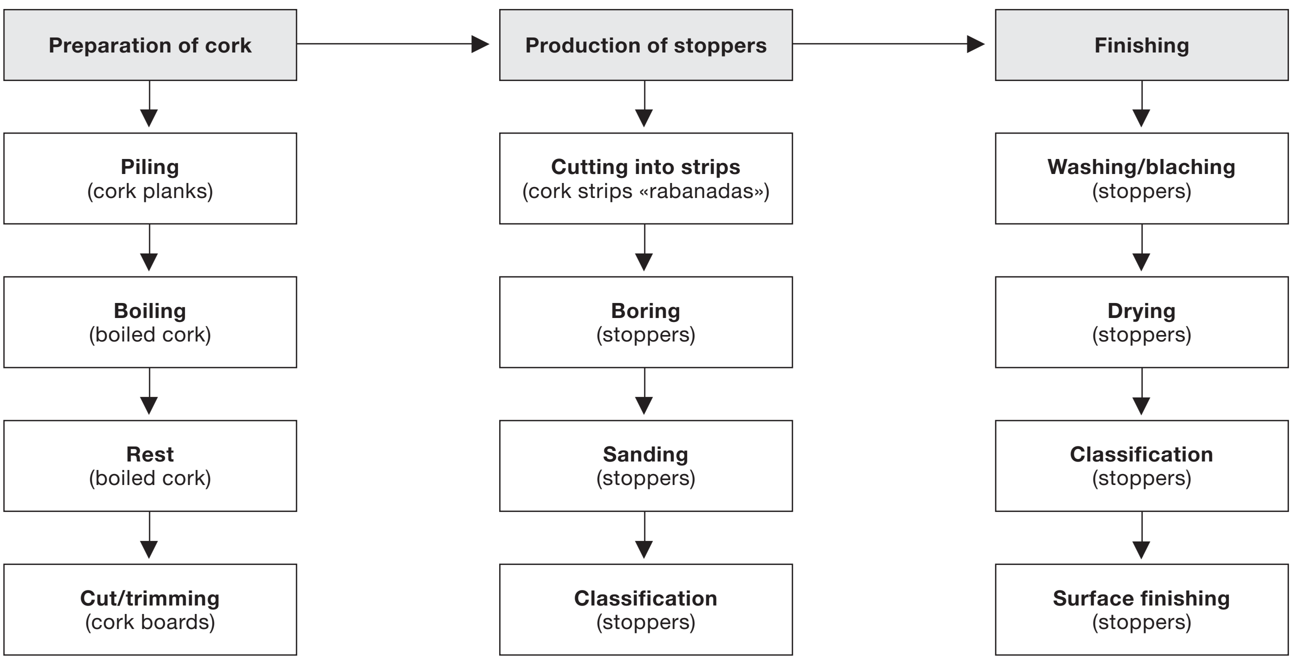

Figure 1. Schematic representation of the industrial process flow-sheet for natural cork stoppers production with main processing steps and products (in parenthesis).

industry. The production yield of stoppers is only 22% to 24% in relation to the cork boards (Fortes *et al.,* 2004; Pereira, 2007). In addition, the cutting of the raw cork planks into cork boards produces on average 5% of by-products (Costa and Pereira, 2004). In fact, considering that the raw cork production also includes a significant amount of planks with insufficient calliper or quality for the boring of stoppers, it results that cork stoppers represent only a small proportion of the initial raw material, which can be estimated at approximately 15%, the rest being taken by the production of cork discs and agglomerates.

It is therefore important to maximize the yield by optimizing the cutting of the boards, since the production yield of stoppers is directly related to the size and shape of the cork board (Costa and Pereira, 2004). In the current practice, the orientation of the cork board cutting is transverse, *i.e.* perpendicular to the tree axis. The height of the resulting cork strips correspond to the axial direction of the tree and the thickness corresponds to the radial direction. In this case, the stoppers are bored in the axial direction of the tree, so that their tops correspond to transverse sections of cork and the cylindrical body comprises all sections between the tangential and radial sections (Fig. 2a).

A prerequisite for yield optimization is the possibility of orienting the cutting direction of cork strips (*rabanadas*) without restriction, namely in the perpendicular direction of the traditional cutting direction (Fig. 2b). Since cork boards are rectangular, with the longitudinally oriented edge (tree axial direction) on average 2.5 times larger than the transverse edge (Costa and Pereira, 2004), a longitudinal cutting will yield more stoppers on boring due to geometrical reasons. In this case, the stoppers will be bored in the tangential direction of the cork board, with the tops in the radial section and the cylindrical body ranging from tangential to transverse sections (Fig. 2b).

This study analyzes the influence of the cutting direction of cork boards (transverse and longitudinal) on the quality profile and porosity characteristics of the stoppers obtained from different quality cork boards. The ability to recognize the two cutting directions by visual inspection of the cork stoppers by expert classification operators was also examined. This is an original prospective study that looks forward to the optimization (and mechanization) of cork board cutting in the natural cork stoppers industrial processing.

Material and methods

Two sets of cork boards were selected in a cork stopper industry comprising 90 boards each, equally divided by three quality classes: $1^{st}/2^{nd}$, $3^{rd}/4^{th}$ and $5^{th}/6^{th}$ (with 30 boards per class), with $1^{st}/2^{nd}$ as the best quality and $5^{th}/6^{th}$ as the worst one. One cork board set was cut into strips transversally (the current method) and the other was cut longitudinally (Fig. 2).

The cork strips (*rabanadas*) from both sets were bored in the axial and tangential direction, respectively from the transversally and longitudinally cut strips, to produce 24 mm × 45 mm stoppers. The stoppers obtained after dimensional adjustment (sanding of tops and cylindrical body) were automatically classified into seven quality classes: from high to low cork stopper

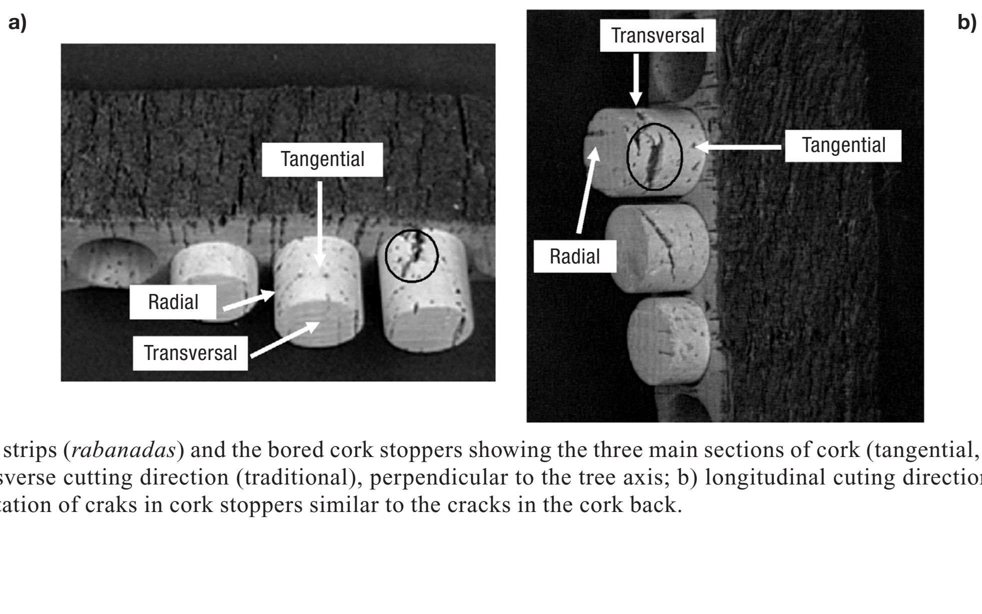

Figure 2. Cork strips (*rabanadas*) and the bored cork stoppers showing the three main sections of cork (tangential, transversal and radial): a) transverse cutting direction (traditional), perpendicular to the tree axis; b) longitudinal cuting direction. Black circles show the orientation of craks in cork stoppers similar to the cracks in the cork back.

quality, respectively Extra, Superior, First (1st), Second (2nd), Third (3rd), Fourth (4th) and Fifth (5th)/Sixth (6th). The number of stoppers produced from the transversally cut cork boards was 3,427 (respectively 1,063, 1,303 and 1,061 from cork boards of 1st/2nd, 3rd/4th and 5th/6th) and 4,003 from the longitudinally cut (1,459, 1,497 and 1,047 from cork boards of 1st/2nd, 3rd /4th and 5th/6th, respectively).

The quality profile of the cork stoppers obtained for each cutting direction was calculated based on the distribution of stoppers by commercial quality class. The economical value was estimated using an Index Value table provided by the industry (Table 1) discriminated by cork stopper quality class, where a price-index was given to each stopper commercial quality class in relation to the price of an Extra cork stopper set at 100. The index value (IV) of cork stoppers obtained from each cork board set was calculated by multiplying the percentage of stoppers in each quality class by the correspondent price-index.

The porosity of cork stoppers obtained from the best quality raw-material (1st/2nd class cork boards) discriminated by the cutting direction (transversal and longitudinal) was quantified by image analysis of the tops and cylindrical bodies, according to the methodology established by Sillero (2002) for the tops and Costa and Pereira (2005) for the bodies. The following parameters were determined: porosity coefficient (CP, %), defined as the ratio between the area of pores and the total area expressed in percentage; average pore area (A, mm^2); number of pores per 100 cm^2 (N_{100}) and average pore orientation (β, °), given by the angle defined by the direction of the maximum diameter of the pore and the xx axis (in the body, perpendicular to the axis of the stopper and in tops, parallel to the growth rings of cork).

The statistical analysis used multivariate methods included in the SPSS® Statistics (v.s. 17.0), mainly exploratory analysis of data and multisample hypotheses and one-way analysis of variance for the seven commercial classes and the two cutting directions.

Table 1. Commercial index value for 24 mm × 45 mm cork stoppers

Quality class of the stoppers	Index value
Extra	100
Superior	90
1st	60
2nd	40
3rd	30
4th	20
5th/6th	20

Table 2. Sample of cork stoppers selected for visual inspection discriminated by quality class and cutting direction, transversal (T) and longitudinal (L)

Quality class of the stoppers	Cutting direction	
	Transversal	Longitudinal
Extra	9 (10%)	13 (11%)
Superior	11 (12%)	16 (14%)
1st	15 (17%)	20 (17%)
2nd	15 (17%)	15 (13%)
3rd	10 (11%)	16 (14%)
4th	14 (16%)	16 (14%)
5th/6th	15 (17%)	19 (17%)
Total	89	115

From the cork stoppers obtained from the transversally and longitudinally cut boards of the best quality raw-material (1st/2nd class cork boards), respectively 1,063 stoppers and 1,459 stoppers, a sample of 204 stoppers was randomly selected in the seven commercial quality classes approximately maintaining the initial proportionality (Table 2). These stoppers were numbered at random and presented independently to two expert classification operators who identified the cutting direction (transversal or longitudinal) by visual inspection and classified each stopper into the seven commercial quality classes.

The degree of accuracy for the identification of the cutting direction was calculated for each operator and for both as a percentage of the real value. A comparison between the economic value obtained using the automatic classification and the classification by visual inspection was also made.

Results

Quality profile of cork stoppers

The quality profile of the stoppers obtained from good quality cork boards showed a higher proportion of good quality cork stoppers, independently of the cutting direction. In average, the 1st/2nd cork boards produced 28% Extra and Superior stoppers, the 3rd/4th cork boards produced 9% and the 5th/6th cork boards only 3% (Table 3).

The cork board cutting direction did not alter the general pattern of the stoppers distribution by quality class although good cork boards (1st/2nd) showed better

Table 3. Production yield of cork stoppers (%) for cork boards discriminated by quality class and cutting direction

Quality class of the stoppers	Transversal cut			Longitudinal cut		
	1st/2nd	3rd/4th	5th/6th	1st/2nd	3rd/4th	5th/6th
Extra	9.6	2.3	0.1	14.9	1.9	0.8
Superior	13.0	9.5	2.5	17.4	3.9	1.9
1st	18.7	16.0	6.0	19.5	11.3	4.7
2nd	14.6	19.8	14.6	13.2	15.0	10.2
3rd	14.8	17.0	14.9	11.8	25.3	13.1
4th	14.5	12.0	13.1	13.2	24.0	16.0
5th/6th	14.9	23.3	48.8	10.1	18.6	53.4

results for the longitudinal cut. In fact, the transversal cut led to 23% Extra and Superior stoppers, while the longitudinal cut produced 32%. On the other hand, the cork boards of medium quality (3rd/4th) produced 12% Extra and Superior stoppers with the transversal cut against only 6% with the longitudinal cut and the 5th/6th cork boards produced 3% for both cutting directions.

The index value of production (IVP) using the quality price-index (Table 1) and the distribution of stoppers by quality classes for the two cutting directions (Table 3) shows that the economic value depends directly from the quality of the cork board. The production values from 1st/2nd cork boards of 48.6 and 55.7, respectively for the transversal and longitudinal cuts, are nearly twice the production values obtained for 5th/6th cork boards (28.6 and 27.2, respectively for the transversal and longitudinal cuts). For the 1st/2nd cork boards the IVP was higher for the longitudinal cut; for the 3rd/4th cork boards the IVP was higher for the transversal cut and for the 5th/6th cork boards the IVP was very similar for the two cutting directions. In general, there were no significant differences between the cork stoppers production value obtained with the two cutting directions (in average 39.3 and 39.1, respectively for the transversal and longitudinal cuts).

Porosity of stoppers

The values obtained for the porosity variables for the seven quality classes of the cork stoppers are summarized in Table 4. The porosity coefficient

Table 4. Mean and standard deviation (in brackets) of porosity coefficient (CP), pore mean area (A), number of pores per 100 cm² (N_{100}) and orientation (β) of the body and top surfaces of cork stoppers discriminated by quality classes.

Quality class of the stoppers	Transversal cut			β (°)	Longitudinal cut			β (°)
	CP (%)	A (mm²)	N_{100}		CP (%)	A (mm²)	N_{100}	
Tops								
Extra	1.4 (0.2)	0.5 (0.1)	3 (0)	48 (4)	0.6 (0.1)	0.3 (0.1)	2 (1)	42 (3)
Superior	2.9 (0.6)	1.0 (0.4)	4 (1)	52 (1)	1.4 (0.1)	0.5 (0.1)	3 (1)	45 (6)
1st	1.5 (0.3)	0.6 (0.1)	3 (1)	51 (2)	1.7 (0.4)	0.5 (0.1)	4 (0)	44 (2)
2nd	2.1 (0.2)	0.6 (0.3)	3 (1)	52 (4)	2.6 (0.9)	0.8 (0.3)	4 (2)	47 (2)
3rd	2.3 (0.5)	0.8 (0.3)	2 (1)	55 (4)	2.7 (0.8)	0.8 (0.1)	4 (2)	46 (1)
4th	2.4 (0.8)	0.9 (1.7)	3 (1)	49 (2)	3.4 (0.7)	0.9 (0.2)	4 (1)	46 (3)
5th/6th	6.7 (0.6)	1.2 (0.2)	5 (1)	54 (2)	4.1 (0.5)	0.9 (0.4)	4 (3)	51 (1)
Body								
Extra	1.0 (0.5)	0.3 (0.2)	4 (2)	56 (5)	1.8 (1.1)	0.4 (0.1)	5 (2)	49 (4)
Superior	1.4 (0.6)	0.4 (0.1)	4 (1)	54 (4)	1.3 (0.5)	0.4 (0.1)	3 (1)	50 (4)
1st	1.5 (0.8)	0.4 (0.1)	3 (1)	55 (7)	2.2 (1.2)	0.5 (0.1)	5 (2)	45 (4)
2nd	2.1 (0.7)	0.5 (0.1)	4 (1)	54 (4)	2.8 (1.2)	0.6 (0.1)	4 (2)	45 (4)
3rd	2.4 (1.3)	0.6 (0.2)	4 (2)	55 (5)	2.8 (1.3)	0.6 (0.1)	4 (2)	46 (4)
4th	2.6 (1.0)	0.6 (0.2)	4 (2)	51 (6)	3.5 (1.8)	0.7 (0.1)	5 (2)	45 (4)
5th/6th	2.4 (1.0)	0.7 (0.2)	4 (1)	53 (3)	3.2 (1.0)	0.8 (0.2)	4 (1)	44 (3)

differed between the quality classes, with stoppers in the best classes showing lower values, independently of the cutting direction. The porosity coefficient of bodies increased, from best to worst quality classes, from 1.0% to 2.4% and from 1.8% to 3.2%, respectively for the transversal and longitudinal cuts.

The ANOVA tests performed for the two cutting directions for the concentration variables, porosity coefficient and number of pores per 100 cm^2, in the stoppers' body showed that the null hypothesis was rejected in all cases and there were significant statistical differences between the cork stoppers quality classes ($P < 0.001$). For the dimension variable average pore area, there were no statistical significant differences between quality classes. The orientation, a shape variable of pores, showed significant statistical differences between quality classes only for the longitudinal cut ($P < 0.05$).

Duncan's multiple comparison tests showed that no homogeneous subsets were achieved for each variable given the significant overlapping between quality classes for both cutting directions. For example the means of the porosity coefficient significantly differed at an alpha level of 0.05 but the following overlapping was obtained between quality classes in the two cutting direction: $\mu\text{Extra} = \mu\text{Superior} = \mu 1^{st} \neq \mu 2^{nd} = \mu 3^{rd} = \mu 4^{th} \neq \mu 5^{th}/6^{th}$.

The influence of the cutting direction on the concentration (porosity coefficient and number of pores) and on dimension (mean pore area) variables of stoppers was found only in the case of the worst quality class ($5^{th}/6^{th}$ class, $P < 0.05$) while in the Extra and Superior quality classes there was no statistical significant difference between the cutting directions. The orientation of pores was influenced by the cutting direction in all the quality classes: in the Extra and Superior classes the differences were significantly different (at an alpha level of 0.05) and for all the others classes the differences were highly statistically different (at an alpha level of 0.01).

Visual detection of cutting direction in cork stoppers

The results obtained for the recognition in stoppers of the cutting direction made by two expert classification operators are shown in Table 5. Overall the boring direction of stoppers, or cork board cutting direction, was accurately identified in 67.2% and 58.8% of the stoppers for operator 1 (Op 1) and operator 2 (Op 2), respectively. The simultaneous identification by both operators (Op 1 + Op 2) was achieved only in 43.6% of the stoppers.

The accuracy or the correct identification of the longitudinal cut was similar in each of the two operators (49.6%) but both operators only identified simultaneously this cutting direction in 26.1% of the cork stoppers. This percentage was significantly inferior to the accuracy of the transversal cut of 66.3% (Table 5).

The overall accuracy found for the longitudinal cut was lower in the best quality classes of stoppers, *e.g.* 43.8% and 26.3% in the 4^{th} and $5^{th}/6^{th}$ stoppers and 15.4% and 18.8% in the Extra and Superior stoppers (Table 5).

Visual inspection of cork stoppers quality

Comparing the results for the cork stoppers quality profiles obtained by visual inspection and by automated

Table 5. Identification match (%) of the cork board cutting direction (transversal and longitudinal) by the observation of cork stoppers (discriminated by quality class) made by two expert classification operators (Op 1 and Op 2)

Quality class of the stoppers	Transvesal cut			Longitudinal cut		
	Op 1	Op 2	Op 1 + Op 2	Op 1	Op 2	Op 1 + Op 2
Extra	100.0	66.6	66.6	38.5	38.5	15.4
Superior	90.9	81.8	72.7	43.8	50.0	18.8
1^{st}	86.6	46.7	40.0	30.0	40.0	25.0
2^{nd}	80.0	80.0	73.3	60.0	46.7	20.0
3^{rd}	100.0	90.0	90.0	68.8	50.0	37.5
4^{th}	78.6	64.2	57.1	56.3	62.5	43.8
$5^{th}/6^{th}$	100.0	73.3	73.3	52.6	57.9	26.3
Total	89.9	70.8	66.3	49.6	49.6	26.1

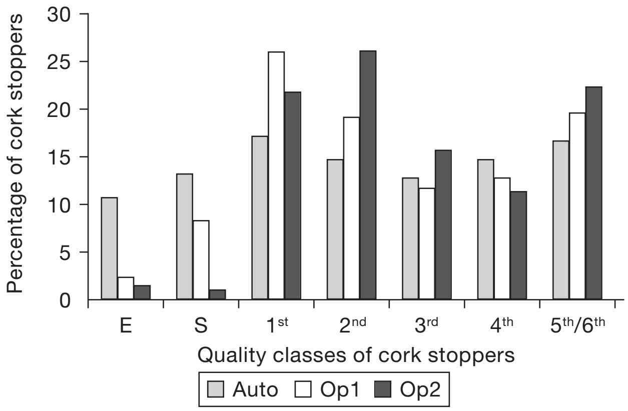

Figure 3. Quality profile of cork stoppers (E-Extra, S-Superior, 1st, 2nd, 3rd, 4th and 5th/6th) obtained by visual inspection of two expert operators (Op 1 and Op 2) and by an automated system (Auto).

vision systems it could be concluded that the visual inspection performed by both operators was more demanding (Fig. 3). Stoppers classified automatically as Extra and Superior were only 1st and 2nd class when inspected visually, and stoppers automatically classified in the 3rd and 4th quality classes were only 5th/6th class for the experts.

The stoppers' distribution by quality class is very similar for both operators who showed a high overall classification match of 83%, with a 93% maximum for the lowest quality and lower values of 75% and 50% for the Extra and Superior classes, respectively. The match between visual and automated inspection was equal to 33% for each of the operators and somewhat inferior (29%) for both operators.

The quality profiles obtained by visual inspection led to a significant decrease of production value yield in relation to the automated system, mainly due to the lower percentage of Extra and Superior stoppers. The production value yield difference was 29% for the most demanding operator (Op 2) and 15% for the other.

The classification match for the two cutting directions was higher for the longitudinal cut e.g. 32.7% against 23.8% for the transversal cut. When discriminated by quality class the match for the longitudinal cut for both operators was higher in the worst quality classes, *e.g.* 68.4% in the 5th/6th class and null in Superior stoppers (Fig. 4). For the transversal cut, on the other hand, it was in the best quality classes that the visual classification match was higher, *e.g.* in Extra

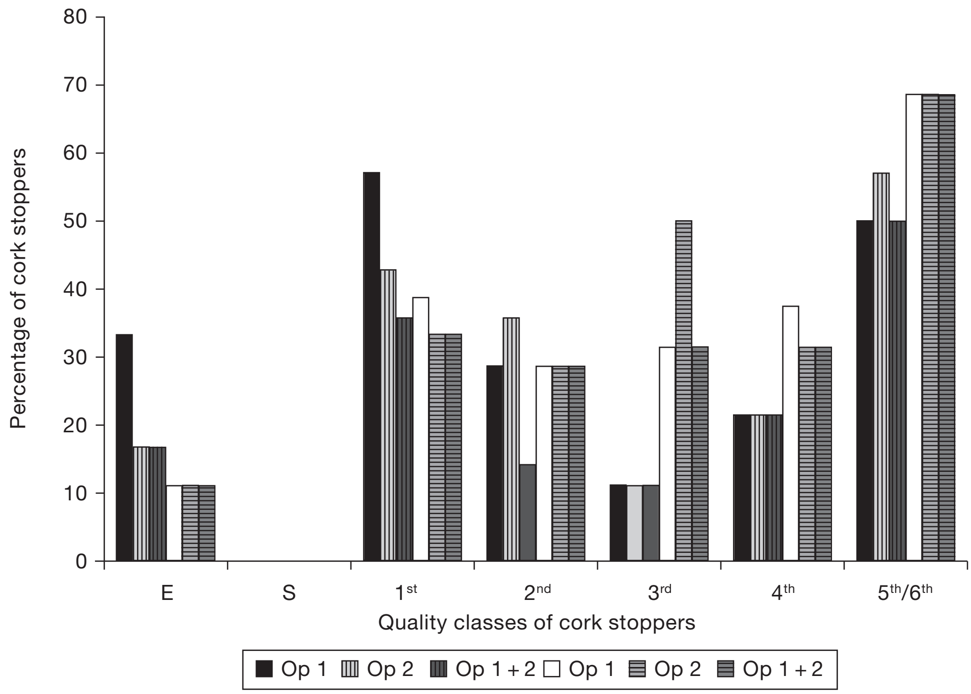

Figure 4. Classification match of stoppers between visual inspection (Op 1, Op 2 and Op1 + Op 2) and an automated system discriminated by cutting direction, transversal (T) (black and vertical lines) and longitudinal (L) (white and horizontal lines) and by cork stoppers quality class (E-Extra, S-Superior, 1st, 2nd, 3rd, 4th and 5th/6th).

and 1st classes respectively 33.3% and 57.1% for Op 1 and 16.6% and 42.9% for Op 2.

The visual distinction of the cutting direction was lowest in the best quality stoppers and maximum in the poor quality stoppers: for the longitudinal cut the match was 11% and 68% for Extra and 5th/6th classes, and equal for Op 1 and Op 2. For the transversal cut the match was 33% and 17% for Extra and 50% and 57% for 5th/6th class, respectively for Op 1 and Op 2 (Fig. 4). This increasing match trend from best to worst stoppers could be related to the more frequent presence of larger pores in the worst quality stoppers that helps to identify the cutting direction by visual inspection.

Discussion

The selection of direction when cutting the cork boards into strips can positively impact net production yields and the stoppers' quality profiles. Due to the original cork board rectangular shape with the longer side in the tree axis direction (Costa and Pereira, 2004), higher cork strips production yield and higher efficiency of raw-material use could be expected with a longitudinal cut.

The results showed that the overall quality profile of the cork stoppers was not significantly influenced by the cutting direction, transversal and longitudinal (Table 3), and consequently, neither was the overall economic production value. However, when considering the quality of cork boards the cutting direction affected the value yield mainly due to a higher proportion of good quality stoppers obtained from the 1st/2nd cork boards and a similar proportion of worst quality stoppers from the 5th/6th cork boards (Table 3).

This fact can be explained by the porosity characteristics of cork, with a typical ellipsoid section of the lenticular channels, with the major axis in the axial direction of the cork board (Pereira *et al.,* 1996). Thus, it is expected that differences between the two cutting directions will be visually detected on the cylindrical surface (body) of the stopper (Fig. 5) as follows:

— With the transversal cut, the porosity in the tangential section appears more or less ellipsoid with the major axis in the direction of the cylindrical axis of stopper, while in the radial or in the in-between sections larger pores will appear because the channels are cut along their longest axis.

— With the longitudinal cut, the porosity in the tangential section is similar to that obtained with the transversal cut with the same ellipsoidal shape but with the major axis perpendicular to the cylindrical axis of the stopper while in the transversal section and in the in-between sections pores will appear smaller because the lenticular channels are cut parallel to the axis of its lower section.

The overall result is that for the best best quality cork boards the longitudinal cut leads to a higher pro-

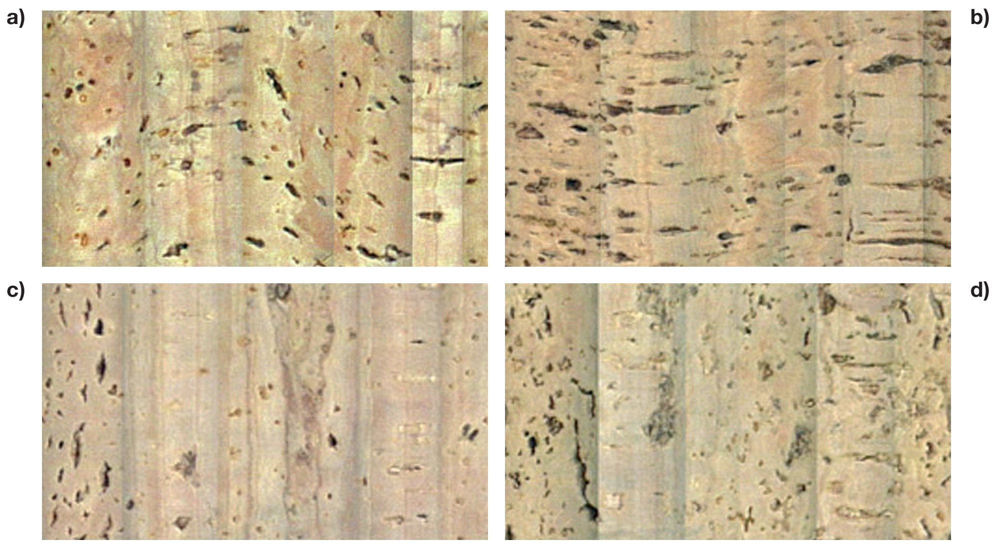

Figure 5. Cork stoppers cylindrical surface (body) for two quality classes: Best (Superior) (a and c) and worst (5th/6th) (b and d). First row for Longitudinal cut and second row for Transversal cut.

portion of good quality cork stoppers, *e.g.* Extra and Superior (32% compared with 23% in transversal cut) in which the lenticular channels are smaller, with a significant reduction of pore area. For medium and poor quality cork boards, the lenticular channels are generally larger, and the key visual factor is their transverse orientation in the stopper's body obtained with a longitudinal cut, therefore impacting the stoppers quality. In fact, statistically significant differences were found between the two cutting directions for the average pore orientation (β) for all stoppers' quality classes.

The porosity that is oriented transversally in the stoppers' body is generally perceived negatively by cork manufacturers. If the cutting direction significantly impacts on the orientation of pores in the stoppers, the expert operators should be able to recognize the longitudinal cutting direction of the cork boards. However, the results showed that this was not true and the operators only recognised this cut in half of the stoppers.

There is a large subjectivity in cork stopper classification (Fig. 3) and the low classification match values found in this study, of about 33%, are similar to previously reported results (Barros and Pereira, 1987; Melo and Pinto, 1988; Pereira *et al.,* 1994). The automated classification is less quality demanding than a manual visual inspection (Fig. 3). In this study the match found between the two operators was higher (82.6%), than the 41.9% reported by Melo and Pinto (1988) and Pereira *et al.* (1994), which could be explained by the fact that operators of the present study were from the same factory and adopted very similar subjective classification criteria.

A classification based on image analysis with selection of quantified features will increase the uniformity within a quality class and the transparency in trade. This lead to suggesting the adoption of objective and standardized decision rules for the classification of stoppers (Costa and Pereira, 2006). However, seven quality classes could not be distinguished with statistically significance, in agreement with previous results (Costa and Pereira, 2005, 2007).

In summary, the results showed a similar overall quality profile of the cork stoppers obtained from strips cut along the two directions, transversal and longitudinal.

Conclusions

The main conclusion of this study is that the cutting operation of cork strips can be optimised and that the selection of direction when cutting the cork boards into strips can positively impact on the net production yields mainly due to the original axial oriented cork board rectangular shape.

In general there were no significant differences between the cork stoppers production value obtained with the two cutting directions. The cutting direction negatively influenced only the cork stoppers of the worst quality classes since the more transversally oriented porosity shown on the stoppers cylindrical surface that is obtained with the longitudinal cutting is generally perceived negatively by cork manufacturers. Nevertheless, the longitudinal cutting of cork planks led to a higher proportion of good quality cork stoppers, which compensates this negative effect.

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