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TRANSMISSION OF IMPACTS DURING MECHANICAL GRAPE HARVESTING AND TRANSPORTATION

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1. Introduction

Harvesting is the most labour-intensive cropping operation in vineyards. The workload can vary from 120 to 250 h ha^{-1}, equal to 25-50% of the annual labour requirements [2]. Manual harvesting, as well as being exacting and time-consuming, can create organisational difficulties linked to finding a labour force. This is a particular problem in vineyards with high production per hectare, but together with limited quality levels and consequent narrower economic margins [1]. In these conditions harvest mechanisation becomes financially indispensable and is suitable for the associated winemaking process provided that the normal quality standards are respected.

Quality problems associated with mechanical harvesting are caused by damage to the berries that mainly becomes apparent with the uncontrolled release of grape juice, often accentuated by a time lapse between harvesting and processing, and in some cases high temperatures [3].

The harvesting affects product quality through direct contact between machine mechanical components and berries. These interactions can be studied using an instrumented sphere for the acquisition and recording of impact dynamic parameters [6]. This type of instrument has frequently been used for evaluating impacts during post-harvest processing. For the harvesting of industrial crops, Brook [5] used an instrumented sphere in potato harvesting machines to correlate the impacts with machine components; Van Canneyt et al. [9, 10] developed an ‘electronic potato’ to evaluate the bruising risk while handling potatoes; Bentini et al. [4] used an instrumented sphere to study the influence of impact dynamics on potato damage. No specific studies have been done on the influence of mechanical grape harvesting techniques on product quality.

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Given the recent spread of mechanical harvesting, the aim of this research was to study the vibrational phenomena to which grapes are exposed to during mechanical harvesting, transportation and delivery to the winery in order to identify the most critical stages for the release of grape-juice and consequent effects on the winemaking.

This type of study can serve as a technical basis for the planning of logistical improvements, technological innovations or the application of treatments to the product aimed at reducing any biochemical anomalies (fermentation and uncontrolled oxidation) resulting from mechanical harvesting [7].

2. Materials and methods

2.1 *Trial design*

The trial was designed to verify the influence of grape harvesting and delivery methods to the winery on product quality. With this aim, the process alternatives hypothesised were harvesting method (manual and mechanical) and type of transport (short-distance on a small trailer and long-distance on a large trailer), thus producing three different treatments for comparison:

A: manual harvesting, transport over a short distance in low-capacity trailers;

B: mechanical harvesting, transport over a short distance in low-capacity trailers;

C: mechanical harvesting, transport over a long distance in high-capacity trailers.

2.2 *Machinery*

For the mechanical harvesting a self-propelled vertical percussion grape harvester was used equipped with a tip-up hopper of 4 m^3 capacity (Figure 1). The percussion head, which can be regulated in height from 1.4 to 2 m, is star-shaped with six oblique spokes, operated during the trial at a frequency of 8.3 Hz. The detached grapes are intercepted by a 4.5 m long horizontal conveyor belt in polyethylene. Product transfer to the hopper is then aided by two horizontal-slatted belts, with the cleaning apparatus, composed of a trimmer and adjustable-speed centrifuge fan, at their point of intersection. The driving-seat and regulation control panel are situated at the top of the machine, next to the percussion head, to facilitate the correct positioning and operating of this fundamental component of the grape harvester.

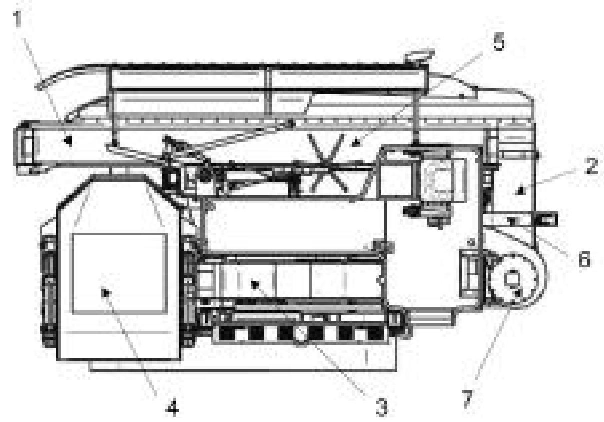

Fig. 1 - Grape harvester used in the trials (from above): 1: interceptor belt; 2: conveyor belt; 3: elevator belt; 4: hopper; 5: star-shaped percussion head with six oblique spokes; 6: trimmer; 7: fan.

For transferring the grapes to the winery two types of trailers were used. For the short-distance transfer (farm winery at 2 km) a single-axle agricultural trailer with a capacity of 3.5 m^3 and maximum loading height of 1.4 m was used, directly loaded by the pickers in the manual harvesting and by tipping up the hopper in the mechanical harvesting. For the long-distance transfer (wine-growers' co-operative at 15 km) a double-axle trailer with a capacity of 12 m^3 and maximum loading height of 1.6 m was used, loaded exclusively with mechanically-harvested grapes.

Oenological processing of the grapes was done in two different-sized wineries (farm-based and co-operative structure) using similar types of mechanisation (emptying into tank, gentle pressing in a horizontal pneumatic press without grape separation from stalks, cold fining and fermentation in stainless steel). To limit the effect on product characteristics to the dimensions of the winemaking machinery alone, the two lines differed only during the phases of emptying into the tank (dimensions of 2 m^3 and 30 m^3) and subsequent pressing (load capacity of 3 m^3 and 20 m^3), the successive operations being carried out in an identical way with micro-vinificators.

2.3 *Trial conditions and product characteristics*

The trials were done on the experimental station at Tebano (Faenza) on the variety Trebbiano Romagnolo (Table 1), which is widely cultivated on the plain and foothills of Emilia Romagna, being used to obtain still table wines or as a base for sparkling wine. Yield is normally high (19 t ha^{-1} for the specifications of Trebbiano Romagnolo D.O.C., EEC Regulation, 1990) and the value of the grapes generally low.

This vine variety was chosen because, in addition to being widely grown in the region, it is increasingly mechanically harvested (for the above-mentioned technical and economic reasons) and the winemaking is scattered in both private farms and co-operative wineries.

The trial was conducted after measuring the yield characteristics reported in Table 2.

Vine variety	Trebbiano Romagnolo
Clone	TR8
Rootstock	SO4
Training form	GDC
Planting pattern (m)	4x1
Year of planting	1994

TABLE 1 - Vineyard characteristics.

Yield (t ha^{-1})	17.5
Yield (kg m^{-1})	3.5
Mass of leaves (g m^{-1})	550
Mass of 100 berries (g)	200
Berry resistance to separation (N)	2.3
Sugar content (°Brix)	21.4
Total acidity (g l^{-1})	4.8
pH	3.1

TABLE 2 - Yield characteristics.

2.4 *Field testing*

The research examined:

Hourly productivity; manual and mechanical harvesting were compared, evaluating machine performance and speed and surveying the unit working times of a squad of grape-pickers in the manual harvesting.

The effects of harvesting method on harvest quality (yield and characteristics of the harvested product, losses and level of defoliation).

The effect of loading and transport of the grapes (container capacity, loading and transport times) on the amount of released juice.

Mechanical stresses on the product from removal from the plant until unloading into the tank at the winery.

Preliminary trials measuring the vibrations transmitted by the grape harvester to the vine were done on plants situated midway between two supporting stakes, by means of a piezoelectric accelerometer fixed on the vine-shoot at 150 mm from the permanent cordon.

The impacts in the machine and during transportation were measured using an instrumented sphere (diameter 0.07 m, mass 0.170 kg) containing a tri-axial accelerometer with a measurement range of ± 4905 m s^{-2} (accuracy 3%). Sampling frequency was 3906 Hz. The system automatically supplied values of peak acceleration, impact duration and velocity during impacts, and the threshold value of acceleration measurement was set at 40 m s^{-2}.

The considered parameters were peak acceleration a_{peak} and integral average acceleration a_{IntAvg} in m s^{-2}. The latter parameter includes information on the variation of speed Δv and impact duration Δt, and is given by Equation (1):

$$a_{IntAvg} = \frac{1}{t_1 - t_0} \int_{t_0}^{t_1} a(t) dt = \frac{\Delta v}{t_1 - t_0} = \frac{\Delta v}{\Delta t} \qquad (1)$$

During harvesting (with no empty hopper) the instrumented sphere was inserted in the product flow, simulating the drop onto the conveyor belt beneath the percussion head, and recovered after falling into the hopper. The instrumented sphere was also used to evaluate the unloading from the hopper onto the trailer. For each treatment the instrumented sphere was inserted in the grape harvester and dumped in the trailer 3 times.

Trials were then done during the transport, using the sphere in a short-distance route (treatment B) and a long-distance route (treatment C). In both cases the sphere was recovered after unloading into the delivery tank so that the dynamic effects of this latter phase could also be evaluated. Treatment A was not taken into consideration for these trials because, with the exception of the loading operations, it involved the same conditions as treatment B.

2.5 *Oenological observations*

The products, after the harvesting, transport and pressing operations had been completed, were processed into wine following the same protocol, carrying out micro-vinifications on the first pressing must.

In order to make an overall evaluation of the effects due to the different management methods of the products a sensorial analysis was done on the bottled wines. Twenty tasters took part in a 'triangular test', 'preference test' and 'sensorial evaluation' between treatment A with respect to treatment B and treatment B with respect to treatment C.

3. Results and discussion

3.1 *Harvesting characteristics*

The characteristics of the manual and mechanical harvesting are reported in Table 3, which shows the strong difference in terms of work productivity, with the obvious consequences on the speed of the operation.

The most obvious differences between the two harvesting methods (Table 4) regard the product remaining on the plant (not-harvested grapes and stalks); however high data variability prevented any significant differences being found between manual and mechanical harvesting, except in the number of grape-stalks remaining on the plant.

Detailed analysis of the composition of the harvested product (Table 5) shows that mechanical harvesting caused obvious damage to the grape skins and the consequent release of juice. Differences between the two methods were highly significant, with the exception of the value related to the presence of leaves and vine-shoots.

A, manual harvesting (short transport); B, mechanical harvesting (short transport); C, mechanical harvesting (long transport).

The three treatments required different loading and transport times, which, however, had no effect on the

Harvesting	Speed ($km\ h^{-1}$)	Impacts ($No\ m^{-1}$)	Work efficie n-cy	Unit workin g times ($h\ ha^{-1}$)	Hourly productiv ity ($t\ h^{-1}$)
Mechanical	2	14.9	0.78	3.2	5.47
Manual				134.6	0.13

TABLE 3 - Operational characteristics of the harvesting.

Harvesting	Product harvested		Product not harvested		Grape-stalks on the plant	
	$kg\ m^{-1}$	CV %	$kg\ m^{-1}$	CV %	$kg\ m^{-1}$	CV %
Mechanical harvesting	3.22	5.13	0.10	48.89	0.05	21.65
Manual harvesting	3.42	1.11	0.05	10.83	0.00	0.00

CV, Coefficient of variation.

TABLE 4 - Quantitative results of mechanical and manual harvesting.

	Type of product gathered			
Harvesting	Cluster fraction P<0.01 ($kg\ m^{-1}$)	Whole berries P<0.01 ($kg\ m^{-1}$)	Grape-juice P<0.01 ($kg\ m^{-1}$)	Leaves and vine-shoots P n.s. ($kg\ m^{-1}$)
Mechanical harvesting	1.18	1.54	0.49	0.01
Manual harvesting	3.18	0.14	0.11	0.00

TABLE 5 - Composition of the harvest from mechanical and manual harvesting; mean values ad analysis of variance.

Measured components					
Treatment	Loading time (min)	Transporting time (min)	Transported load (t)	Released grape-juice (%)	Grape temperature (°C)
A	200	10	3.0	3.3	24
B	36	10	3.0	15.3	23
C	130	50	11.3	18.4	24

A, manual harvesting (short transport); B, mechanical harvesting (short transport); C, mechanical harvesting (long transport).

TABLE 6 - Working times and characteristics of the transported loads.

temperature of the transported loads (Table 6). As regards the release of grape-juice, there is only an appreciable increase with respect to the value measured at the end of harvesting in treatment C, due to the longer distance and higher-capacity trailer.

3.2 *Measurement of mechanical stresses*

Preliminary trials done with the accelerometer while the machine was in transit [8] recorded a mean of 25 accelerations above 50 m s^{-2} and a maximum value of 170 m s^{-2} on the grape-bearing vine shoot.

The data obtained with the instrumented sphere were statistically analysed.

Table 7 gives the result of the analysis of variance for the dynamic parameters measured on the grape harvester, where treatments B and C refer to the two mechanical harvests cited in Materials and Methods. There are no significant differences, which is in agreement with the type of trial, which should only differ by type of transportation.

Figures 2 and 3 show the pattern of accelerations inside the grape harvester for the two treatments.

There is an analogous behaviour between the two treatments (the peaks point out that the interactions between sphere and cleaning apparatus are staggered by a few tenths of a second, but this is compatible with a possible difference of sphere insertion in the product flow).

	Peak acceleration a_{peak},(m s^{-2})		Integral average acceleration a_{IntAvg},(m s^{-2})	
	F-Ratio:	P-Value:	F-Ratio:	P-Value:
	0.71	0.4014	0.58	0.4476
Treatment	Mean	Std. Error	Mean	Std. Error
B	331	111	107	23
C	470	121	133	25

TABLE 7 - Analysis of variance for the accelerations measured with the instrumented sphere during the harvest (95.0% confidence level).

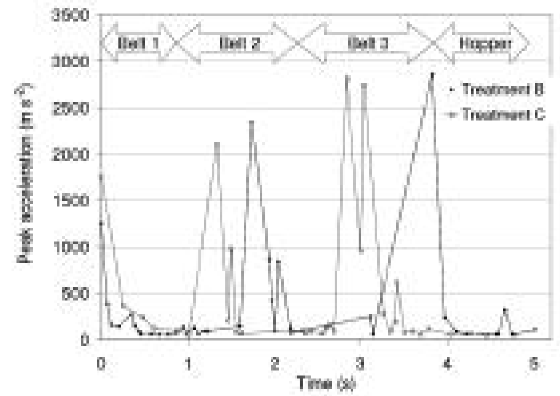

Fig. 2 - Example of peak accelerations measured with the instrumented sphere inside the grape harvester; Belt 1: interceptor belt; Belt 2: conveyor belt; Belt 3: elevator belt; treatment B: mechanical harvesting (short transport); treatment C: mechanical harvesting (long transport).

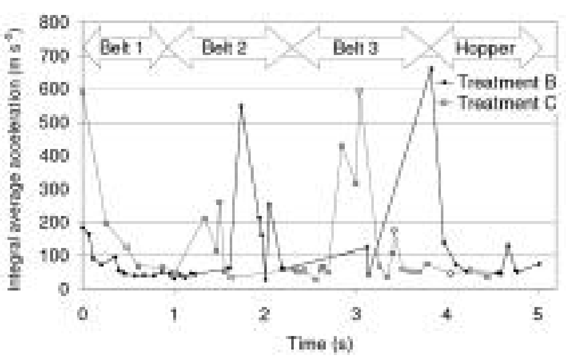

Fig. 3 - Example of integral average accelerations measured with the instrumented sphere inside the grape harvester; Belt 1: interceptor belt; Belt 2: conveyor belt; Belt 3: elevator belt; treatment B: mechanical harvesting (short transport); treatment C: mechanical harvesting (long transport).

Comparison of the accelerations reveals no substantial differences between the two treatments in the temporal trend of peak accelerations and integral average accelerations (Figures 2 & 3).

The transit times of the product inside the grape harvester are approximately 5 seconds.

Table 8 shows the result of analysis of variance for

	Peak acceleration (a_{peak}), m s^{-2}		Integral average acceleration (a_{IntAvg}), m s^{-2}	
	F-Ratio:	P-Value:	F-Ratio:	P-Value :
	0.05	0.8181	0.10	0.7537
Treatment	Mean	Std. Error	Mean	Std. Error
B	147	43	62	14
C	135	33	67	11

TABLE 8 - Analysis of variance for the accelerations measured with the instrumented sphere during hopper unloading (95.0% confidence level).

the dynamic parameters measured during hopper unloading onto the transport trailers, treatments B and C again refer to the two mechanical harvests cited in Materials and methods. Once again there are no significant differences.

Comparison of the trials in the grape harvester and those of hopper unloading onto the means of transport demonstrates a clear reduction in impact intensity during the latter.

The pattern of accelerations during hopper unloading is represented in Fig. 4. The two treatments show very little similarity in the temporal trend of accelerations because of the different container size and, presumably, a different positioning of the sphere in the load.

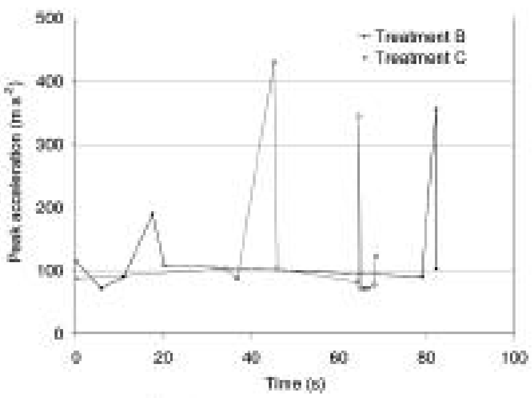

Fig. 4 - Example of peak accelerations measured with the instrumented sphere during hopper unloading onto the means of transport: treatment B: mechanical harvesting (short transport); treatment C: mechanical harvesting (long transport).

The duration of the operations is approximately 70 – 80 seconds.

During transportation, vibrational phenomena of average magnitude are recorded with no significant differences between treatments (Table 9). The temporal trend of accelerations is similar in the peaks recorded while loading, while there is a much higher peak in the unloading of treatment C, corresponding to the trailer emptying into the bigger delivery tank at the wine-growers' co-operative (Fig. 5).

	Peak acceleration (a_{peak}), m s^{-2}		Integral average acceleration (a_{IntAvg}), m s^{-2}	
	F-Ratio: 0.99	P-Value: 0.3238	F-Ratio: 0.79	P-Value : 0.3785
Treatment	Mean	Std. Error	Mean	Std. Error
B	143	28	66	8
C	193	32	74	7

TABLE 9 - Analysis of variance for the accelerations measured with the instrumented sphere during transportation (95.0% confidence level).

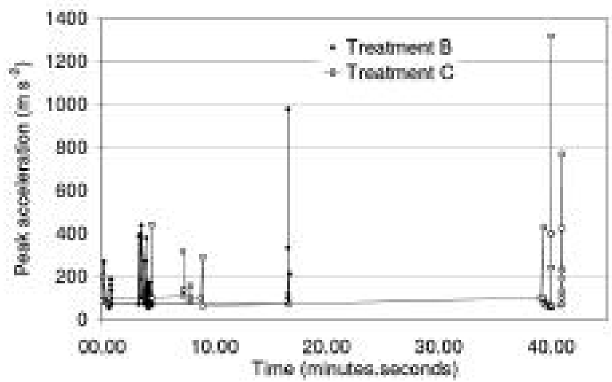

Fig. 5 - Example of peak accelerations measured with the instrumented sphere during transportation (from loading in the field to emptying in the winery): treatment B: mechanical harvesting (short transport); treatment C: mechanical harvesting (long transport).

Analysis of the pattern of measured stresses (Fig. 6) shows that the maximum intensities were recorded in the grape harvester, whilst the values halved during transportation, but with a higher number of impacts recorded. The least critical situation, for number and low intensity of stresses, is on the plant, where harvesting by vertical percussion acts without direct contact with the vine-shoot and relatively low stresses.

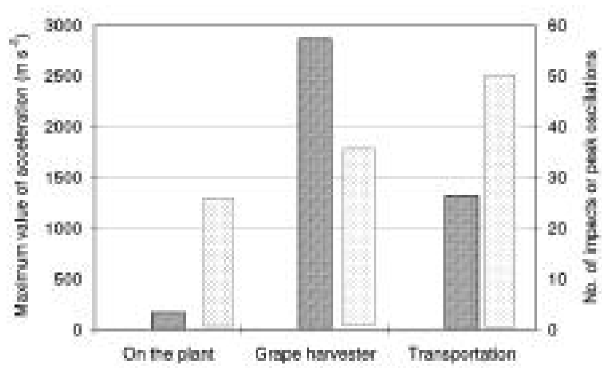

Fig. 6 - Maximum intensities and number of stresses measured in the different phases from harvesting to delivery at the winery; maximum intensity; number of stresses.

3.3 *Oenological evaluations*

Evaluation by the triangular test demonstrated significant organoleptic differences (p=0.01) between the three wines examined.

In the direct comparison, no significant difference emerged from the preference test in terms of a comparison between manual and mechanical harvesting (8 preferences for treatment A, against 12 for treatment B), whereas the preference indicated by all the tasters was significant (p=0.01) for the short transport (treatment B with respect to treatment C).

The sensorial analysis expressed the following evaluations:

– the treatment A (manual harvesting) was without defects, slightly anonymous and acidulous to the taste;

– the treatment B (mechanical harvesting and short transport) appeared to be without defects, fairly fine, but slightly altered;
– the treatment (mechanical harvesting and lengthy transport) showed slight oxidation defects, apparent in an altered aroma and more intense colour.

4. Conclusions

Mechanical harvesting, although of undoubted advantage in terms of productivity and speed, modifies the grapes, with disintegration of the clusters, the release of grape juice and a small accumulation of plant impurities. A modest increase in the released grape juice may also be caused by transportation in large containers. The greater amount of released grape juice recorded in mechanical than manual harvesting increases oxidation of the product, with effects on the organoleptic characteristics of the wines, such as altered taste sensations (treatment B) and more marked oxidation (treatment C).

The investigation of the vibrational phenomena, which can be reasonably correlated with grape damage, demonstrates impacts of high intensity in the interactions with the mechanical parts of the grape harvester, much higher than the stresses registered on the vine when picking. The stresses decrease in intensity during transportation, where the operations of loading and unloading at the winery appear to have importance.

The two treatments of mechanical harvesting show no significant differences in intensity of the impacts, in either the harvesting operations or transport, where the size of the trailers and length of journey have little effect.

In the light of these results, it can be hypothesised that the most critical stage of mechanical harvesting could be the delivery times to the winery, which must be kept as short as possible to avoid oxidation of the partly-damaged product. In support of this strategy, which is not always easily implemented because of the scattered positions of the vineyards and organisation of the workforce, modifications could be made to the machine construction (protection of the points of impact) and regulation (improved control of belt speeds), or by treatments to the harvested product, such as with sulphur dioxide or chilling, which would increase the stability of the must.

5. References

[1] ARRIVO A., BELLOMO F., D'ANTONIO P., *Limiti di convenienza per l'impiego delle macchine operatrici. Applicazione a macchine mono e polifunzionali per la viticoltura [Convenience limits of implement employment. Application to mono and multifunction implements for grape growing]*, Rivista di Ingegneria Agraria (2001), 32(3), 147-157.

[2] BALDINI E., INTRIERI C., *Meccanizzazione della vendemmia e della potatura [Mechanization of grape harvesting and pruning],* Editrice CLUEB (1984), Bologna.

[3] BALDINI E., INTRIERI C., *Viticoltura meccanizzata [Mechanized grape growing]*, Editrice Edagricole (2004), Bologna.

[4] BENTINI M., CAPRARA C., MARTELLI R., *Harvesting damage to potato tubers by analysis of impacts recorded*, Biosystems Engineering (2006), 94(1), 75-85.

[5] BROOK R.G., *Impact testing of potato harvesting equipment*, American Potato Journal (1993), 70, 243-256.

[6] KLUG B.A., TENNES B.R., ZAPP H.R., *Analysis of impacts recorded with an instrumented sphere*, Transactions of ASAE (1989), 32(3), 1105-1110.

[7] PEZZI F., BORDINI F., ARFELLI G., *La raccolta meccanica del Trebbiano Romagnolo: influenza di differenti tecnologie sulle caratteristiche dei vini [Mechanical harvesting of Trebbiano Romagnolo: influence of different technologies on wines features]*, Atti Convegno SIVE (2005), Piacenza, (1), 47.

[8] PEZZI F., BERARDINELLI A., BORDINI F., GIUNCHI A., RAGNI L., *Raccolta meccanica dell'uva: uno studio sulle correlazioni tra qualita' del lavoro, condizioni operative e trasmissione delle vibrazioni alla pianta [Mechanical harvesting of grape: a study on the correlation between working quality, operating conditions and vibrations transmission to the plant]*, Rivista di Ingegneria Agraria (2005), 36(4), 25-34.

[9] VAN CANNEYT T., TIJSKENS E., RAMON H., VERSCHOORE R., SONCK B., *Characterisation of potato-shaped instrumented device*, Biosystems Engineering (2003), 86(3), 275-285.

[10] VAN CANNEYT T., TIJSKENS E., RAMON H., VERSCHOORE R., SONCK B., *Development of a predicitive tissue discolouration model based on electronic potato impacts*, Biosystems Engineering (2004), 88(1), 81-93.

SUMMARY

The aim of the research was to study vibrational stress on grapes during mechanical harvesting, transfer and delivery to the winery, in order to identify the most critical stages and the consequent effects on the winemaking.

An instrumented sphere was used to evaluate and memorise the impacts in the grape harvester and means of transport.

Three treatments, obtained by differing harvesting method (manual and mechanical) and transport type (short and long distance), were compared. A correlation was sought between the transmitted stresses and characteristics of the harvested product.

The effects on product quality were evaluated by chemical analyses of the musts and sensorial analysis of the end-product, vinified using the same procedure.

Key words:
Mechanical harvesting, mechanical vibrations, quality, losses.