Comparison between Traditional and Industrial Plants Used for Production of "Carasau" Bread and Evaluation of Final Products

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Introduction

In recent years there have been clear structural weaknesses in the typical bread production sector in Sardinia, Italy. While the demand for the products has been constantly increasing, the organization of production in traditional plants has lagged behind. This is mainly because of the small size of the bakeries, the difficulty of transforming a traditional production process into a semi-industrial or industrial one, and the problems involved in incorporating new technological innovations into the process. Increasing demand for the products means that there must be improvements in both quality and quantity. This will result in the productive systems becoming more complex and, consequently, the quality control systems for the production lines themselves must become simpler and easier to use. Although the traditional breads sector in Sardinia suffers from the problems described above, there is also clear room for development. "Carasau" bread (fig. 1) is a fundamental part of the diet of a large part of Sardinian population. Its physical characteristics facilitate the development in the product of non-enzymatic browning reactions. It is widely recognised both nationally and internationally (Lerici and Nicoli, 1994; Nicoli et al., 1997a; Nicoli et al.,1997b; Manzocco et al., 1998; Manzocco et al., 2000) that these reactions are beneficial for the health of the consumers. As is well-known, baking of bread causes a series of physical, chemical, and biochemical changes in the dough, as well as changes in color. The latter are generally considered one of the principal signs of quality (Hansen and Hansen, 1996; Nicoli et al., 1997; Lerici and Nicoli, 1998; Coppola et al., 1999). In the case of pane "carasau" the changes in color take place during three stages of production: "Gonfiatura" (rising) or first baking (fig. 2), when the fermented dough rises, the separation of the leaves of bread into two halves (fig. 3), and finally "carasatura" or second baking (fig. 4), when the bread is dried out.
This work presents the results of a study carried out in one traditional and one semi-industrial plant. The study evaluated not only the operating characteristics of the machinery but also the capacity, quality of the bread, and organization of the work.

Materials and Methods

Both the bakeries studied (Gambella and Paschino, 2004) contained the following machines: kneaders, separators, and moulders. The semi-industrial plant also used a cutting machine. The bread was baked in a wood-fired oven in the traditional plant and in an electric tunnel oven in the semi-industrial one (fig. 5).

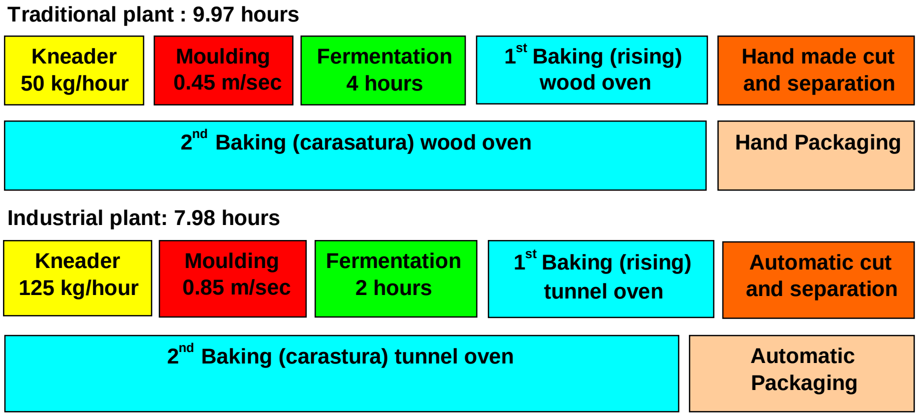

Figure 5. Operational time needs to produce "carasau" breads in the plants.

Characteristics of the Machines

Milled and remilled mono-variety semolina flour (named Simeto) was used to prepare the dough in both bakeries. In the traditional plant the kneader had a capacity of 50 kg/h, and in the semi-industrial plant of 150 kg/h. In the traditional plant the dough was cut and separated by hand at an average velocity of 0.45 m/s. In the semi-industrial plant an automatic separating machine was used which had a speed almost double that of the traditional plant (0.85 m/s). The moulder used in both plants could form 1320 discs/h. In the traditional plant the dough was fermented in wooden tubs covered with linen sheets, while in the semi-industrial plant it was fermented in 5-kg stainless-steel containers with lids. The wood-fired oven in the traditional plant had a fixed floor with a vault of refractory bricks. The smoke from the burning wood was removed by extraction fans. The internal dimensions of the oven varied from 1.50 to 2.50 m in depth for the platforms and the vault hemispheres were from 40 to 70 cm in height. The thermal potential of the electric oven was 36.5 kW while the wood-fired oven was 70 kW. In the latter, a perfectly homogenous temperature could not be maintained because of many different factors involved. These included the low quality of the wood used, the loss of heat by radiation through the walls of the oven, and the metal components (i.e. the oven door and the observation door). The electric tunnel oven did not suffer from these drawbacks as it was completely automated and of the correct dimensions for optimizing the heat flow, which was thus both rapid and rational. In addition, the temperature was controlled separately in the upper and lower parts of the oven, and the rate of movement of the conveyor belt could be programmed manually and observed on a digital display unit.

Analysis

The working capacity of the plant, the operating efficiency of the machines, the efficiency of the workers, and the electricity consumed per unit of production were calculated by measuring the following parameters: the theoretical working capacity of all the machines used according to the manufacturer's specifications, the total work time in each phase of production, the real total production, the number of workers, the energy consumed, and the quantity of electricity and heat used in each phase of production.

Experimental Design and Statistics Used

In order to reach their daily production targets, two productive cycles were necessary in the traditional plant and three in the semi-industrial plant. Each cycle included all the phases of the production process. In the traditional plant there was a further work cycle so that the samples used in the statistical analysis were uniform. The work capacity of the individual workers was calculated as:

Work capacity per worker (kg/h) = Operational Capacity (OC)/number of worker in the phase

where OC (operational capacity in the single phase) was calculated as a function of OT (Operational Time) and AT (Additional Time). OT is the working time of the worker and was calculated as the sum of the effective time (ET) and the additional time (AT). Both of these were taken analytically. AT was equal to 5% to 10% of OT and was the range of variations of extra time for each single phase. Operational efficiency (μc) was determined from the relationship between the operational capacity (OC) and the theoretical capacity (Ci) of each single machine in the phases of the production process**Error! Objects cannot be created from editing field codes.**. Daily consumption or (Dc) was determined on the basis of the Electrical Power Installed (EPI = kW) and the operating time (OT) for each single phase Dc = EPI (kW) × OT.

The energy used for the daily production (Wh/kg) was calculated by dividing the daily consumption (kWh/day) by the quantity of product produced. The incidence (I) was calculated as the relationship between the energy for unit production (EUP) in each single phase and the total consumption of energy **Error! Objects cannot be created from editing field codes.**.

The time, the worker's capacity, and the consumption were statistically analyzed by Student's T-Test (Statgraphics). The table shows the overall daily production values of the two plants. The following chemical parameters were measured: pH, total acidity, dry matter, water activity, and antioxidant activity. These were determined in the dough and the finished product and the samples analysed were homogenized in a Waring - 4L centrifuge. An average of four samples were taken at each point when analyzing: the dry matter (DM) (Official Methods of Analysis of the Association of Analytical Chemist; 1995), pH, total acidity (TA), expressed in grams of acetic acid for 100 gm of dry matter (Quaglia, 1984), water activity (aw) at 25°C, (Rotronic, hygromer, AwVC, Karl Fast) and antioxidant activity (Brandt-Williams, 1995). All the data were also statistically analysed, using MSTA-C (Michigan State University, East Lansing, Mich.) software, and by ANOVA, using the Student Test to find the mean.

Results and Discussion

Labour Used

The number of labor used (table 1) was different in each phase and depended on the operational capacity of the production line, even though 15 workers were used in each plant. In the traditional plant, daily production was 109.1 kg and the workers were employed equally in all phases of production, with the exception of kneading, where only one worker was used. In the semi-industrial plant the work force was mainly employed in separation of the sheets and the "carasatura." The planned daily production was 300 kg/day.

Table 1. Number of workers used in producing pane "carasau."

Operation	Traditional	Semi-industrial
Kneading	1	1
Preparing the leaves of dough	3	1
Moulding	2-3	1
"Gonfiatura" - rising - first baking	2	1
Cutting and separating the leaves	3	7
"Carasatura" – baking - second baking	3	4
Total	15	15

Work Time and Working Capacity

The total time for each single operation (table 2) shows that there were substantial differences in the time used for each operation in the two types of bakeries. Daily capacity in the traditional bakery was reached after 9.97 h, while in the semi-industrial plant it was reached after 7.98 h, even though the amount of bread produced was almost three times as great. Looking, in more detail, at the time taken for each single operation, it becomes clear that cutting and separating were the most time consuming operations in both types of bakery. In the semi-industrial plant 41% of the total time was used for this, while in the traditional plant this figure rose to 52%. Baking was the most rapid part of the operation: "gonfiatura" (rising) and "carasatura" (baking) used 1% or less of the total time. Moulding in the traditional bakery took 2 h per day if maximum daily capacity was reached. In the semi-industrial plant this operation took 0.8 h or, in other words, 60% less time, even though only one worker was employed on it. Cutting and separating took 3.30 h in the semi-industrial plant and 5.20 h in the traditional plant. In this case the number of workers employed certainly made a difference: seven in the semi-industrial plant and three in the traditional one. There was a significant difference between the two plants in the operating capacity for the single operations. Kneading took place at 90 kg/h in the semi-industrial plant and at 50 kg/h in the traditional plant and "gonfiatura" (rising) at 30 kg/h in the semi-industrial plant and at 6 kg/h in the traditional one. "Carasatura" (baking) in the traditional plant also took place at 6 kg/h. Obviously the hourly production of the workers was also affected by the above figures. In the traditional plant this varied from a maximum of 50.1 kg/h in kneading to a minimum of 0.6 kg/h in baking, with production during moulding being 2.4 kg/h and that during cutting and separating 13.1 kg/h. Hourly production of the workers was: 90 kg/h for kneading, 49.5 kg/h for forming, 11.7 kg/h for cutting and separating and 13.5 kg/h for baking (table 2). The figures for hourly production per worker during moulding were also lower in the traditional plant than in the semi-industrial one (2.40 kg/h vs. 27.70 kg/h). The operating efficiency of the machines kneading and preparing the leaves in the traditional plant was 100% while in the semi-industrial plant machines were operating at 67% and 50% efficiency, respectively. By contrast the moulding machines and the oven in the traditional plant were only working at 30% and 40% efficiency, respectively, while the figures for the same machines in the semi-industrial plant were 74% and 78%. The difference in efficiency in the moulding machines was due to the fact that the machine was fed automatically in the semi-industrial plant and by hand in the traditional plant. The lower capacity in the traditional plant had its greatest impact on the efficiency of the moulding, cutting and separating. Obviously all of this was in direct relationship to the operating capacity of each single phase. In the traditional plant two cycles were necessary to achieve the daily production target, while five cycles were necessary in the semi-industrial plant.

Table 2. Total time, capacity, operating efficiency, and working cycles in the two plants.

Phase	Plant	Total Time (h)	Capacity		Operating Efficiency (c)
			Operating (kg/h)	per worker (kg/h)	
Kneading	Traditional	0.67 ± 0.01[a]	50.33 ± 2.52	50.33 ± 2.52	1.00
	Semi-industrial	1.67 ± 0.01	90.00 ± 4.36	90.00 ± 4.36	0.67
Preparing the leaves of dough	Traditional	2.00 ± 0.005	24.67 ± 2.42	15.06 ± 0.13	1.00
	Semi-industrial	2.20 ± 0.002	50.35 ± 0.77	49.50 ± 0.35	0.50
Moulding	Traditional	2.00 ± 0.0002	10.05 ± 0.33	2.40 ± 0.20	0.40
	Semi-industrial	0.80 ± 0.005	51.92 ± 0.12	27.73 ± 0.06	0.74
"Gonfiatura" - rising	Traditional	3.00[b] ± 0.002	6.06 ± 0.14	0.60 ± 0.02	0.30
	Semi-industrial	16.00[c] ± 0.06	30.16 ± 0.19	20.10 ± 0.02	0.67
Cutting and separating the leaves	Traditional	5.20 ± 0.01	13.08 ± 0.24	13.13 ± 0.03	-
	Semi-industrial	3.30 ± 0.005	40.03 ± 0.05	11.73 ± 0.08	-
"Carasatura" - drying	Traditional	3.00[b] ± 0.6	6.00 ± 0.06	0.60 ± 0.02	0.30
	Semi-industrial	16.00[c] ± 0.01	39.02 ± 0.02	7.48 ± 0.47	0.78
Total and median time	Traditional	9.97	109.10	6.70	-
	Semi-industrial	7.98	299.30	20.70	-

[a]Median ± standard deviation.
[b]Time in minutes.
[c]Time in seconds; between the row in column three, four and five the differences are higher to $p > 0.05$.

Energy Consumption

Energy consumption varied greatly from machine to machine (table 3). Greatest consumption was by the ovens, which consumed 70.00 kW in the traditional plant and 36.50 kW in the semi-industrial one, and lowest by the moulders which consumed 0.37 kW in the traditional plant and 0.45 kW in the semi-industrial plant.

Table 3. Electrical Power Installed (EPI), daily energy consumption (Dc) per machine, and energy used per unit of production (EUP), and incidence (I) for each phase in the two plants.

Machine	Plant	EPI (kW)	Dc (kWh/day)	EUP (Wh/kg)	I (%)
Kneader	Traditional	2.75	1.84	18.42	0.26
	Semi-industrial	5.00	8.35	27.83	2.71
Preparing the leaves of dough	Traditional	3.50	7.00	70.00	0.99
	Semi-industrial	3.50	7.70	25.67	2.50
Moulder	Traditional	0.37	0.74	7.40	0.10
	Semi-industrial	0.45	0.36	1.20	0.12
Oven	Traditional	70.00	697.90	6979.00[a]	98.66
	Semi-industrial	36.50	291.27	970.90[a]	94.66
Energy in total	Traditional	-	22.62	7074.82	-
	Semi-industrial	-	16.50	1025.60	-

[a]The energy was calculated by considering the total time that the ovens were used from the beginning to the end of production in the two plants (9.97 h in the traditional and 7.98 in the semi-industrial plant). Between the row in column four and five, the differences are higher to $p > 0.05$.

Daily energy consumption was linked to how long the machines worked and how much energy they consumed. In the traditional plant it varied from 0.74 kWh/day for the moulder to 697.90 kWh/day for the oven. This was because the oven was working throughout the whole production period. Similar results were found for the semi-industrial plant. The moulder consumed the least energy (0.36 kWh/day) and the oven used the most energy (970.90 Wh/day). The energy consumption per unit of production was as follows: from a minimum of 1.20 Wh/kg for the moulder to 6,979.0 Wh/kg for the oven in the traditional plant, and from 0.12 Wh/kg for the moulder to 970.90 Wh/kg for the oven in the semi-industrial plant. Thus baking consumed most energy in both plants. The next highest consumer was the moulder in the traditional plant (2.50 Wh/kg) and the kneader in the semi-industrial plant (2.71 Wh/kg.). These results were confirmed by the percentage incidence of total energy consumption. The oven consumed 98.66% of energy in the traditional plant and 94.66% in the semi-industrial one.

Chemical and Physical Parameters and Antioxidant Activity

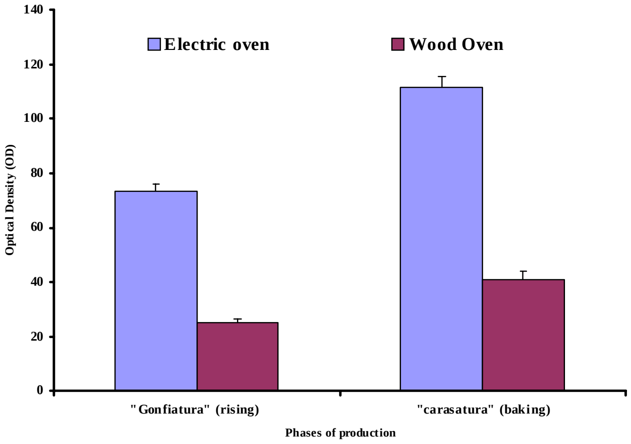

Figure 6. Comparison between (CBA) in the two products at the end of rising and baking.

The quality of the remilled semolina will be established in a future article by comparing it with samples of single-milled semolina from the mill. The chemical and physical parameters of the bread from the two plants were studied to see if these were altered by the type of plant. Normally in traditional plants the fermentation was obtained with different micro-organisms (yeast and lactobacilli). These characterize the bread, depending on the length of the fermentation period (4-6 h). In this work the micro-organism used for the fermentation of the dough in both plants was yeast (S. cerevisiae). The results obtained (table 4) show that fermentation reduced the pH values and acidity. This reduction was directly linked to the greater hydrolysing capacity of the carbohydrates in the semolina, which was itself due to the action of the enzymes and their consumption by micro-organisms (Coppola et al., 1999). At the end of fermentation the acidity values in both samples of bread were 0.43 g of citric acid per 100 g of dough. There was also good production of organic acids. These improve the aroma of the bread and help with the formation of glutens. The data are directly connected to the reduction of pH at the end of fermentation (4.4 units). This caused the dough to mature rapidly. Dry matter was 94.6% of the finished product and water activity (aw) was 0.22 in the traditional plant while the corresponding values for the semi-industrial plant were 93.5%, 0.37. The antioxidant activity (fig. 6) in baked products was greater in the electric tunnel oven (111.7 × 10-5 DO-3/min-1/mg dm–4) than in the wood-fired oven (17.8 × 10-5 OD-3/min-1/mg dm–4). There were no differences in the color of the final products at the end of the "carasatura" baking, regardless of the temperature used in the oven. Informal sensory evaluation trials did not find any marked differences between the breads obtained from the two plants.

Table 4. Principal chemical and physical parameters found in the traditional and semi-industrial plants.

Chemical and Physical Parameters of "Carasau" Bread	Plant	End of Dough Making	End of Yeast Growth	"Gonfiatura" Rising	"Carasatura" Drying
pH	Traditional	6.01[a] ± 0.01	5.31 ± 0.02	5.27 ± 0.03	5.58 ± 0.02
	Semi-industrial	5.90 ± 0.03	5.31 ± 0.10	5.47 ± 0.30	5.48 ± 0.06
Acidity T.T. (g. acetic acid/100g d.b.)	Traditional	0.20 ± 0.06	0.46 ± 0.04	0.46 ± 0.04	0.46 ± 0.07
	Semi-industrial	0.21 ± 0.05	0.43 ± 0.02	0.46 ± 0.11	0.42 ± 0.12
Dry matter (%)	Traditional	60.70 ± 0.01	60.90 ± 0.05	69.21 ± 0.03	93.52 ± 0.28 a[b]
	Semi-industrial	61.70 ± 0.30	59.90 ± 0.10	69.21 ± 0.05	94.69 ± 0.14 a
Water activity (aw)	Traditional	0.95 ± 0.01	0.95 ± 0.02	0.91 ± 0.03	0.37 ± 0.01 b
	Semi-industrial	0.98 ± 0.03	0.95 ± 0.03	0.91 ± 0.01	0.22 ± 0.03 b

[a]Median ± standard deviation.
[b](a, b) = median with the same letter indicate respectively values of p > 0.001.

Conclusions

The machinery and plant that are used at present in small- and medium-sized bakeries cause great discontinuities in the process. These seriously effect the work capacity and thus also the productivity of the workers. Thus introducing plant and processing systems which can incorporate different phases of the production process would result in concrete rationalisation of working capacity, of productivity of the workforce and of electricity consumption. Mechanization of the process allows the bakery to increase its productive capacity by uniting the quality of traditional products with the advantages of semi-industrial plants. The introduction of the correct criteria when deciding which machines to use would resolve the problems linked to increasing hourly productivity of the plant and the workforce. Here one must bear in mind: the new plant available which can transform a traditional production cycle into a semi-industrial or industrial one, the use of machines for specific tasks, the rationalization of the working areas inside the plant, and the use of multi-functional machines. All of these can be employed without reducing the high quality of the final product. Comparison of the two types of plant at the end of fermentation found that there were no statistically significant differences in the acidity of the bread, the pH, or the dry matter content and that the adoption of a semi-industrial system did not modify the chemical and physical characteristics of the final product, with the exception of aw and the antioxidant activity of the Maillard reaction products. [The primary antioxidants or "free radical scavengers" (or with "chain breaking" activity) are molecules which can interrupt the propagation of radicals thanks to their capacity to add a hydrogen atom (or a single electron) to free radicals (Gordon, 1990) Among the compounds with antioxidant activity, the Maillard reaction products (MRPs) have an anti-mutagen effect due to their anti-oxidizing capacity (Lerici et al., 1997; Nicoli et al., 1997).] These were higher in the products from the electric tunnel oven than they were in the wood-fired oven. The working capacity and the productivity of the workforce were indubitably higher in the semi-industrial plant, and this is clearly of great economic importance for the bakery.

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