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QUALITY MAINTENANCE PERFORMANCE AND RESISTANCE TO *TRIBOLIUM CASTANEUM* AND *PLODIA INTERPUNCTELLA* PENETRATION OF AN ALTERNATIVE PACKAGING MATERIAL FOR SEMOLINA

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ABSTRACT

Insect attacks to food packages are a major concern for food producers, who are often blamed for being responsible for the occurrence of contamination which seriously affects the image of the company. Wheat semolina is commonly packed in paper bags, which do not always offer sufficient protection against insect pests. The present research evaluated the performance of a new packaging alternative, consisting of paper laminated with polypropylene (P+CPP), in terms of resistance to penetration by two common cereal product pests, namely *Tribolium castaneum* and *Plodia interpunctella*, and quality maintenance of the packaged product. Neither of the two pest species tested were able to pierce the P+CPP, while no differences were observed in the time required to penetrate other materials. Moreover, quality parameters, namely pH, acidity and color, did not differ significantly among samples packed in different materials. The new P+CPP combination is a promising alternative for the packaging of semolina, because it offers improved protection against pests compared with conventional materials, while maintaining the paper-appearance of traditional packaging.

- Key words: insect pests, packaging, *Plodia interpunctella*, quality parameters, shelf-life, *Tribolium castaneum*, wheat semolina -

INTRODUCTION

Packaging is critical for preserving food quality and is the final defence against insect pests. Insect infestations are the main cause of loss in packaged foods both in terms of direct damage (MULLEN, 1994) and the extra costs required to preserve and package foods (HANLON *et al.*, 1998). Consumers tend to think that food manufacturers are responsible for any insect contamination, independent of their real involvement (HOU *et al.*, 2004). The argument has been addressed by several Authors, who evaluated the ability of insects to penetrate packaged foods (ESSIG *et al.*, 1943; GERHARDT and LINDGREN, 1954, 1955; BATTH, 1970; CLINE, 1978a) and to assess the resistance of various packaging materials (SREENATHAN *et al.*, 1960; DOMENICHINI and FORTI, 1975).

Packages have several points of weakness and almost every packaging material can be perforated by insects. Penetration depends on various factors, depending on the insect and the packaging variables. Among the former, species and life stage of the insects involved must be considered (CLINE, 1978a; 1978b; BOWDITCH, 1997; ROBERTSON, 1993; RIUDAVETS *et al.*, 2007). Regarding the packaging features, the nature and structure of the packaging material, the combination of materials and the package design play a key role with respect to insect penetration. Package design parameters, such as folds and seals, can be points of weakness and may facilitate the formation of holes which offer preferential access to the package contents. Consequently, the design of a suitable package for each type of product is crucial for quality maintenance and an extended shelf-life. Recently, there has been an increased availability of different materials for food packaging, particularly multilayer films, which combine various materials (e.g. aluminium and paper with different polyolefines). Researchers continuously try to improve the quality of complex multilayer films to guarantee food safety (RIUDAVETS *et al.*, 2007). The quality of the package seal is also fundamental for protecting foods from insect infestations. Even packages that are perfectly sealed can be attacked by insects, that are attracted to the product by volatiles that permeate through the material (BROWN, 1992; NAVARRO *et al.*, 2007). A study by YERINGTON (1978) demonstrated the direct correlation between the package seal and the level of infestation.

The most destructive insect pests of stored products belong to the Orders Coleoptera (beetles) and Lepidoptera (moths) (ROBERTSON, 1993) and can be subdivided into "penetrators" and "invaders" (HIGHLAND, 1984). Penetrators bore holes through packaging materials. An example is the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera Pyralidae), which is considered responsible for 98% of food infestation worldwide (SÜSS and LOCATELLI, 2001). Invader insects enter packages through existing holes; the red flour beetle *Tribolium castaneum* (Herbst), is an example (HIGHLAND, 1991). The presence of this pest in flour for 2 to 3 months permanently alters its quality (SÜSS and LOCATELLI, 2001). The above-mentioned subdivision however, should be considered with caution, because in some conditions invaders can behave as penetrators and vice versa (CLINE, 1978a; CLINE and PRESS, 1990; BOWDITCH, 1997).

Packaged foods can be attacked during the production phase or in the subsequent phases of distribution, such as transportation and storage in warehouses, retail stores (TREMATERRA, 2009), and the home.

Durum wheat semolina is the main ingredient of pasta, and is used in the Mediterranean area for bread-making and in the preparation of pizza. It is commonly commercialized in kraft paper which, despite being the most widely used material for flours and semolina, does not provide sufficient protection against pest infestations and absorption-desorption of moisture.

The aim of the present work was to assess the resistance of various materials commonly used to preserve flour and semolina, to the penetration of *P. interpunctella* and *T. castaneum.* In addition, a new combination of packaging materials for durum wheat semolina was evaluated. This alternative to the traditional kraft paper bags could extend the shelf-life of semolina and ensure resistance to pest attacks. The new bilayer material (paper laminated with cast polypropylene) was developed to satisfy the technical requirements of producers (i.e. printability, machinability, etc.), to fulfil the expectations of consumers, who are accustomed to packages with a "paper look", and to improve the overall performance in terms of quality preservation and resistance to external agents.

MATERIALS AND METHODS

Rearing conditions

Tests were carried out using adults of *T. castaneum* and third and subsequent instar larvae of *P. interpunctella.* The colonies of the above-mentioned insects were established in the laboratory of the Dipartimento di Scienze e Tecnologie Fitosanitarie of the Università di Catania in 2001, from specimens collected from infested wheat flour. The colonies are routinely reared in glass jars (25 × 17 cm), maintained in climatic chambers with a constant temperature of 23°±1°C, 70±5% RH and a L8:D16 photoperiod and are fed wheat flour. Three months before the experiment, a part of the *T. castaneum* colony was reared on durum wheat semolina to accustom the insects to this diet. *P. interpunctella* were continuously fed on durum wheat semolina.

To obtain similar experimental conditions, mature larvae of *T. castaneum* were collected and groups of 100 insects were put into plastic Petri dishes (9 cm diameter × 2 cm high), in which they were maintained until the adult stage. Second instar larvae of *P. interpunctella* were isolated in the same way and used in the experiment when they had reached the third instar.

Packaging materials

The packaging materials used for the tests were: kraft paper alone (P), bioriented polypropylene laminated with coextruded polypropylene (BOPP+PP), cast polypropylene alone (CPP), and kraft paper coupled with cast polypropylene (P+CPP). The materials tested with their thickness and water vapour transmission rate (WVTR) values are reported (Table 1). Paper bags were used as received and were identical to the ones commonly used for marketing semolina. The other bags were made in our laboratory and had the same dimensions as the kraft paper ones (13 cm × 12 cm × 4 cm). Packages, made in our laboratory, were made from reels of test materials; three seals were applied, one for each short side (top and bottom) and one on the back side of the bags, using an industrial machine. The bags were filled with 250 g semolina, bought from a local mill and visually inspected to exclude the presence of insects and, then, hermetically sealed using a method commonly used for commercial packaging.

Penetration tests

The test evaluated the ability of adult *T. castaneum* and *P. interpunctella* larvae, to pierce and consequently penetrate the packaging materials. Insects collected from the colonies were grouped in plastic Petri dishes (40 individuals of each species). Thirty adults of *T. castaneum* and third instar larvae of *P. interpunctella* were randomly chosen and transferred into transparent plastic cages (30 cm × 18 cm × 6 cm), each containing the semolina packages made with the different materials. Penetration tests were carried out using five cages, each containing 30 insects of each species. Experiments were repeated three times, at 35-day intervals. The investigation was carried out from October 1st 2008 to the end of January 2009.

The tops of the cages were covered with a fine mesh nylon screen to assure ventilation. Each container was provided with 15 g of wheat flour to feed the insects after the start of the trial and to stimulate them to search further food in order to survive. All cages were kept in a climatic chamber at a constant temperature of 23°±1°C and 70±5% RH and in the dark to provide a favourable environment for pests.

Packages were examined daily for the first month and 3 times/week thereafter and the test was considered finished when the first hole was observed. The viability of the insects and their activity towards the packages were monitored. The pouches were visually inspected through the cages; there was no manipulation in order to avoid disturbing the insect activity. This procedure was effective because most of the pest attempts were made at the same places on the bags, i.e. seals and folds, which were exposed to the observer's view. The packages were monitored for a few days after the end of the trial in order to assess pest behaviour in package colonization. Insects that died within the first 72 h were replaced in order to maintain a constant number.

Shelf-life test

The assessment of the resistance of the new material to pest penetration should be considered together with its performance in terms of quality maintenance which was carried out by a parallel shelf-life simulation test of semolina packed in the various test materials. Samples were stored for five months at 22°C and 22.7% relative humidity. The following chemical-physical parameters were monitored at 30-day intervals: moisture content, pH, acidity and colour. Moisture content was determined by drying 10 g semolina at 130°C until constant weight. The pH was measured on 4 g semolina to which 100 mL of previously neutralized 50% ethanol were added, mixed and decanted for 3 h before filtration through filter paper. Acidity, expressed as mL of 1 N NaOH necessary to neutralize 100 g semolina, was determined by titration of 50 mL filtrate with 0.5 N NaOH, using phenolphthalein as indicator. CIE Lab colour parameters were determined with a portable colorimeter NR-3000 (Nippon Denshoku Ind. Co. Ltd., Japan) with an illuminant type C/2°, previously calibrated with a white tile.

Table 1 - Packaging materials tested, with relative water vapour transmission rate (WVTR), density (for paper) and thickness values.

Material	WVTR	Density/Thickness
P	8482 g/(m^2 24 h)	30 g/m^2
CPP	13.18 g/(m^2 24 h)	30 µm
BOPP+PP	3.06 g/(m^2 24 h)	25 µm + 30 µm
P+CPP	1.19 g/(m^2 24 h)	30 g/m^2 + 30 µm

Statistical analysis

The time of penetration into the different packages of the species tested was analyzed using a one-way-analysis of variance (ANOVA) and the Student's t-test ($p \leq 0.05$) was used for post-hoc comparison. Statistical analysis was performed using STATISTICA 8 for Windows (StatSoft Inc., 2008).

RESULTS AND DISCUSSION

Microscopic inspection of the package surfaces carried out at the end of each trial, revealed numerous abrasions on every material tested, indicating the attempts of insects to pierce and penetrate the packages. On the whole, the coupled materials were more resistant to penetration. Table 2 reports the results relative to the time required for the insects to penetrate the semolina packages made with the different materials. Kraft paper was pierced by both insect species considered: *T. castaneum* needed a minimum of 12 days with an average of 16.0±3.6 days, to penetrate the packages. In one replicate, *T. castaneum* did not find a suitable point of surface weakness for a successful attack. In one case, the larvae of *P. interpunctella* needed 9 days to pierce the packages, but on the average the species needed more days to penetrate (20.2±7.4) than *T. castaneum*. However, the difference in time needed for penetration among the species was not statistically significant ($F=1.45$; $df=5.77$; $p>0.05$). CPP packages showed little resistance to pests. Even if the times were different, both insect species were able to penetrate the packages. Larvae of *P. interpunctella* were quicker (minimum 9 days) than *T. castaneum* (15 days), but on the whole, there were no significant differences ($F=1.76$; $df=6.60$; $p>0.05$). This finding disagrees with that of CLINE (1978b), who found PP to be the most resistant to the attack of *P. interpunctella* larvae and *T. castaneum* adults. This contrasting result cannot be explained by the thickness of the package, given that the PP used by CLINE (1978b) was thinner (24 μm) than the one used in the present experiment (30 μm). With regards to *T. castaneum*, a possible explanation could be that the observation time was less, but this is only a hypothesis considering that the Author did not specify the length of time of the trial with the Coleoptera adults. Moreover, the Author reported that PP was bored only by adults of *Lasioderma serricorne F.* and *Trogoderma variabile* Ballion (Coleoptera Dermestidae).

Table 2 - Time required (days) for the insects to penetrate the semolina pouches made with different materials.
No significant differences were found.

	P	CPP	BOPP+PP	P+CPP
Tribolium castaneum				
1	12	15	13	-
2	-	24	18	-
3	19	18	16	-
4	18	22	15	-
5	14	17	20	-
	16.0±3.6	19.2±3.7	16.4±2.7	-
Plodia interpunctella				
	P	**CPP**	**BOPP+PP**	**P+CPP**
1	29	9	-	-
2	9	19	-	-
3	19	11	-	-
4	24	17	-	-
5	20	23	-	-
	20.2±7.4	15.8±5.8	-	-

Only *T. castaneum* succeeded in penetrating the BOPP+PP bags. On the average, penetration was achieved in 16.4±2.7 days, with a minimum of 13 days required to complete their attack on the material, which was pierced in correspondence with the seal zone. This was evidently a point of weakness of the package made with this material which was probably due to the change in structure caused by the sealing temperatures. This species showed a typical behaviour, in which the individuals scout the whole area carrying out isolated attempts to pierce the surface. DOMENICHINI (1996) observed that if an individual finds a suitable place, other individuals would be drawn to it and together they would concentrate their efforts to penetrate the package. Conversely, *P. interpunctella* did not succeed in getting into the packages, which demonstrates that this material can protect the food from this species.

The results of the experiment showed that the P+CPP bi-layer was the most resistant to the insect attacks. The package surfaces and seal zones showed some abrasions but no species succeeded in piercing them. This result could be due to the lack of release of volatile odours, the primary factor of attraction for insect pests (BARRER and JAY, 1980; DAVIS and PETTITT, 1999) that are fundamental in the selection of a favourable place of development. The scarce release of volatiles from the new packaging material could prevent infestations.

In assessing the suitability of a new material or packaging solution, all of the aspects involved in food preservation should be considered with special regard to protection from external agents and quality maintenance of the packaged product. The shelf-life test of packaged semolina considered three main quality parameters: pH, acidity and colour. The shelf-life test highlighted similar performances for all the plastic materials tested. With the exception of the pa-

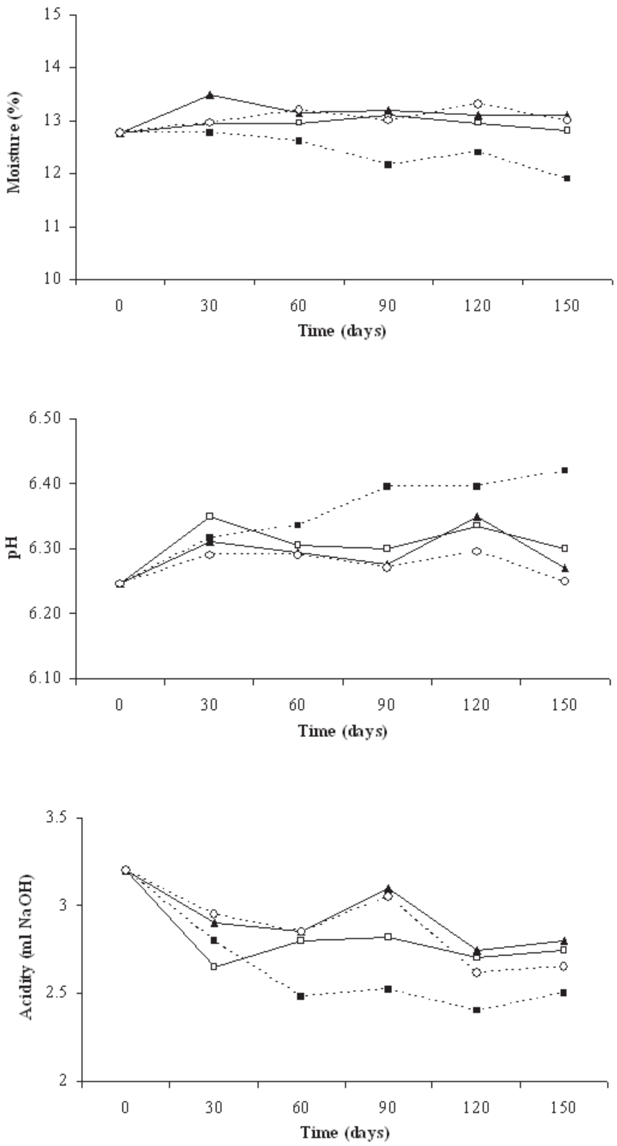

Fig. 1 - Changes in the values of moisture content, pH and acidity of semolina packed in different materials, as a function of storage time. P(■), CPP(○), BOPP+PP(□), P+CPP(▲).

per bags which, as expected, showed the highest moisture loss (i.e. around 6.5%), due to the highest WVTR (Table 1), all of the other materials preserved the initial moisture content of the semolina (Fig. 1). The final moisture content of semolina packed in paper bags (11.9%) was significantly lower than that of semolina packed in the plastic materials (12.8-13.1%); no significant differences were observed among the latter. The pH and acidity values (Fig. 1) did not vary significantly throughout the storage time for samples packed in plastic packages, with only slight decreases in the acidity values. The pH and acidity values were practically the same among all the samples packed in plastic throughout the sampling period. Only semolina packed in paper bags showed significantly higher pH values after 60 days until the end (150 days) of storage, compared to the other samples. Differences observed for samples packed in paper bags compared to CPP, BOPP+PP and P+CPP could be attributed to the much higher permeability of the former material to organic acids, CO_2 and low-molecular-weight compounds, which caused the increase in pH. Finally, the colour parameters (Fig. 2) were characterized by a similar trend (i.e. slight increase) during shelf-life, and no significant differences were observed among the samples packed in different materials.

CONCLUSIONS

Studies on food packaging and materials used to prevent insect infestations are of particular relevance for the food industry and the distribution system. Insect-proof packaging can help reduce the use of insecticides to lower the risk

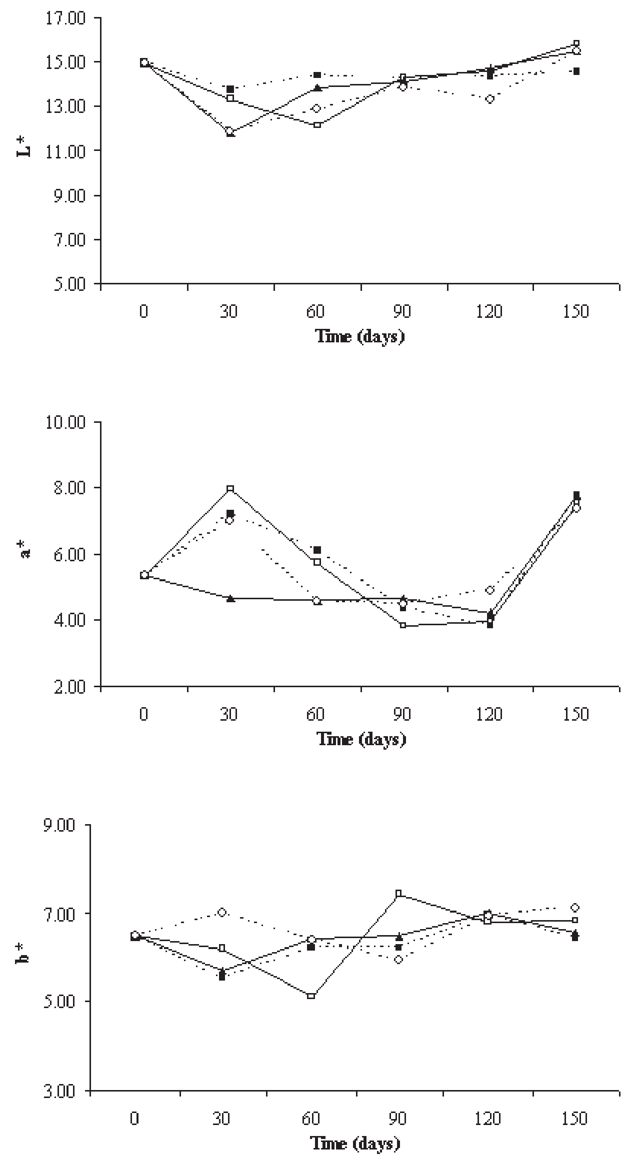

Fig. 2 - Changes in the CIE Lab colour parameters L* (lightness index), a* (red index) and b* (yellow index) in semolina packed in different materials, as a function of storage time. P(■), CPP(○), BOPP+PP(□), P+CPP(▲).

of food losses due to insect contamination. Until recently, pesticides were the most frequently used method to avoid it, but these are dangerous and have been banned in most parts of the world. The present study focused on the ability of *P. interpunctella* larvae and *T. castaneum* adults to pierce materials used for the packaging of semolina, considering that these two species are the most common pests in stored food. The results show differences in the resistance of materials but not in the time required for the two different species to pierce packages. No significant difference was observed among the materials pierced (P and CPP) in terms of time required by the insects to penetrate the packages. On the other hand, BOPP+PP was pierced only by *T. castaneum*, while the new bi-layer P+CPP was not pierced by the species tested. Quality parameters did not differ significantly among samples packed in the different materials. The new P+CPP combination could be a promising alternative for the packaging of semolina, offering an improved protection against pests compared with conventional materials while maintaining the paper-appearance of the traditional packages.

The trials performed in the present research are useful for testing the resistance of packaging materials to insects and choosing the best materials for the packaging of pasta, cereals and other products that are subject to insect attacks, such as bakery products, powdered milk, tea, etc. Further work is needed to determine the permeability of materials to volatiles and to study the correlations between this parameter and the susceptibility of packages to insect attacks. Among the technical specifications of a material for food packaging, data concerning the permeability to aroma compounds are needed.

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