Infestation of wheat flour by flour beetles (*Tribolium castaneum*) affected in its chemical and toxicological properties and validity for human consumption

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Abstract:

Wheat flour represents a significant worldwide food. In many Asian and African countries including Egypt, big quantities of the flour are stored in open shounas and/or shades. Under such conditions, flour is subjected to attack by various biological factors including insects. The tenebrionid beetles such as *Tribolium confusum* represents an important species of the insect pests of wheat flour. Therefore, the present study aims to investigate the chemical and toxicological properties of wheat flour as affected by flour beetles (*Tribolium castaneum*) infestation as well as its validity for human consumption. Twenty seven jars, 1 kilogram, of flour (extraction 82%) were used filled with wheat flour 82 % extraction. A100 larvae of *Tribolium confusum* were put into each jar and 15 jars, not infested, were kept as control. The samples were kept for the trial duration (2, 4, 6, and 8 weeks) at 25 ^{0}C and 60% of relative humidity. At the end of this period, all samples were sieved to recover the insects and then analyzed. The obtained data indicated that, in the end of infestation periods (8 weeks), chemical alterations include a significant ($p \leq 0.01$) increasing in flour fat characteristics such total acidity and peroxide values which recorded 49.60 and 94.08% compared to 3.13 and 1.75% for the uninfested/control samples, respectively. The opposite direction was recorded for the iodine number. On the other side, infestation of wheat flour with insects leads to increase in quinones and malonaldehyde content, which represent some of the most extensively studied toxic, mutagenic and carcinogenic compounds, that significant ($p \leq 0.01$) increased by the rate of 264.71 and 26.53% compared to 1.02 and 2.04% for the uninfested/control samples, respectively. The same trend was observed with uric acid, as excretion of arthropods and main reason for the gout disease in human; and ergosterol, a steroid involved in some biochemical process in insects and mould metabolite. In conclusion, all of these data means lipids of wheat flour become rancid as a consequence of oxidation and oxidative rancidity initiated by infestation with insects after 6 - 8 weeks of infestation. Also, the presence of significant amount of the determined toxic compounds in infested wheat flour with beetles that introduced by substantial quantities into the bakery products may be represented a great concern/hazard for the community health.

Keywords: wheat flour, insects' infestation, flour beetles, fat characteristics, uric acid, malonaldehyde**,** quinones**,** ergosterol

Introduction

Wheat flour is representing a significant worldwide food. In many Asian and African countries (including Egypt), the majority of flour are stored outside the silos i.e. in open yards (shounas and/or shades). Under such conditions, flour is subjected to attack by various biological factors such as pest insects. Under such conditions, flour is subjected to attacks by various biological factors such as pest insects. Almost people in such countries may use flour infested with pest insects in their bread and backing products. The tenebrionid beetles i.e. *Tribolium confusum* represent an important species of the insect pests of wheat flour. Flour suffered infestation by these insects can be affected in its hygienic parameters. Each change depends on many variables, for example the type of wheat, the pest species, the infestation level, and the environmental conditions. This insect is one of the most common occurring in situation were grain products are stored. It is one of the most annoying pests in retail grocery stores and ware houses and extremely serious in flour mill infested material well show many elongate reddish-brown beetles about 1/7 inch (3.6 mm) long , crawling over the material when it is disturbed and brownish – white somewhat flattened six –legged larvae feeding on the inside of the brain kernels and crawling over the infested seeds. They are generally known among millers as “bran bugs”.

Previous studies indicated that flour extracted from wheat that has suffered infestation by insect pests such *Tribolium confusum* could be affected in its nutritional, chemical, and rheological characteristics. Each change of these factors depends on many variables, such as the type of wheat, the pest species, the infestation level, and the environmental conditions (Ahmed *et al*., 1982; Domenichini *et al*., 1994; Pagani *et al*., 1994; Nasr, 1998 and Abd El-Hameed, 2002).). Within the last three decades, there is an increasing international concern about the presence and the adverse effects of some toxic compounds in flour as a consequence of infestation with pest insects during storage. Some of these toxic compounds include fat oxidative products (El-Farra *et al*., 1982, and Nasr, 1998). Also, Ladisch, (1967) reported that the defensive gland of flour beetles were found to secrete a mixture of toxic quinones. The flour in which these beetles have built up a large population becomes pink in color because of contamination by their secretions. Many studies indicated that some of these compounds secreted by the common flour beetles have the

ability to induce carcinogenic and toxicological effects on mammalian body (El-Mofty *et al.*, 1988, 1989 and 1992; and Abd El-Hameed, 2002). Those authors also indicating that the temperature of the oven in which the biscuits were baked did not alter the carcinogenicity of the infested flour.

All of these studies indicated that infestations by pest insects and their influence on the hygienically parameters of wheat flour is not a new issue but still require much further studies. Therefore, the present study aims to investigate the changes in some chemical and toxicological properties of wheat flour as a consequence of pest infestation (*Tribolium confusum)*. Also, the correlation's between the levels of these changes in chemical and toxicological properties of wheat flour and the elongation of the pest infestation periods were also in the scope of this investigation.

Materials and Methods

Materials

Fresh wheat grains (variety red wheat, *Triticum vulgare*) were obtained from the local markets of Benha Governorate, Egypt during the harvesting season, 2018. The samples were transported to the laboratory and stored immediately in the refrigerator at 0 ^{0}C until using in preparation of flour.

Flour beetles *Tribolium confusum* (*Tenebrionidae: Coleoptera*), were collected from the infested wheat present in open Shouns proper to the Holding Company for Rice and Flour Mills (HCRFM), Ministry of Supplies, Benha, Egypt.

Specimens of *Choetospila elegans* Westw. (*Hymenoptera: Pteromalidae*), used for biological monitoring, was obtained from Plant Protection Dept., Faculty of Agriculture, Mansoura University, Mansoura, Egypt.

Jars, capacity one kilograms and food grade container, were purchased from the local markets of Benha City, Benha Governorates, Egypt.

Equipment's

Throughout this study a SP Thermo Separation Products Liquid Chromatograph (Thermo Separation products, San Jose, CA, USA) was used with a Consta Metvic 4100 pump, a Spectra Series AS100, Spectra System UV 1000 UV/Visible Spectrophotometer Detector, Spectra System

FL 3000 and a PC 1000 system software. The columns used (Alltech, Deerfield, IL, USA) were a Hypersil BDS-C18 (5 µm, 150 x 4.6 mm I.d.).

Methods

Preparation of wheat flour

The wheat grains samples were taken from the refrigerator and sieved to get rid of any foreign matters or dust. Kernels were then dried to below 10 % moisture content and was then adjusted to the moisture content required which was 14%. The quantity of water added to the quantity of grains to reach the level 14% moisture content was according to the formula mentioned by Ahmed *et al.*, (1982). The grains was milled using laboratory mill and sieved through 60 and 50 mesh screen to obtain wheat flour with extraction rate 82 %.

Examination of the wheat flour samples with insects and insecticides residues

Biological monitoring was first carried out to ensure that the wheat flour samples were not already infested, and contained no residual insecticides according to the methods of Domenichini *et al*., (1994) as the following:

For insecticides residue testing, specimens *of Choetospila elegans Westw.* (Hymenoptera: Pteromalidae), which is very sensitive to insecticides residues, were used in this investigation. Four 100 g samples of flour to be used in the experiments were placed in petri dishes (15 cm diameter), plus 10 specimens of *Choetospila elegans Westw*. Over a period of three weeks, almost all of these specimens of insects were survived.

For insects residue investigation, five hundreds grams sample of flour to be used in the experiments were placed in petri dishes (15 cm diameter) and incubated at 25 0C with 60 % humidity. Over a period of five seven weeks, all of these dishes were examined by using lens (20 X), and they were free against insects' residue.

Experimental design

Twenty seven jars, one kilogram of wheat flour (82%) were used and divided into two main groups. For the infested group, 100 larvae of *Tribolium confusum* were put into each jar and 15 jars, not infested, were kept as control group such as shown in Table (1). The infested flour

samples were kept for the trial duration at 25 ^{0}C and 60% of relative humidity. At the end of each tested period, these samples were sieved to recover the insects and then analyzed.

Table (1): Experimental design

Groups	Sample/Jar Number	Sample type	Number of insects	Duration time
Control group	1-3	not infested	-----	0 day
	4-6	not infested	-----	14 days
	7 – 9	not infested	-----	28 days
	10 – 12	not infested	-----	42 days
	13 - 15	not infested	-----	56 days
Infested group	16-18	*T. confusum*	100	14 days
	19-21	*T. confusum*	100	28 days
	22-24	*T. confusum*	100	42 days
	25-27	*T. confusum*	100	56 days

Chemical properties/Fat constants determination

Total acidity (TA, mg KOH.100^{-1} g sample), peroxide value (PV, meq.100 g^{-1}) and Iodine number (IN, g) were determined using the methods described in A.O.A.C. (1995).

Uric acid determination

Uric acid (UA) was analyzed according to the method mentioned by Stroev and Makarova (1989).

Ergosterol determination

Ergosterol (Er) was determined by adaptation the method of Schwadorf and Muller (1989) using HPLC with fluorescence detector.

Quinones determination

Quinones (Qu) was extracted, purified, separated and determined in flour samples according to the method mentioned in Naoya and Naotaka (2014) using HPLC with ultraviolet and fluorescence detectors.

Malonaldehyde determination

Malonaldehyde (MDA) content was determined using thiobarbituric acid reagent (TBA)such as described by Woyewoda *et al.*, (1986). In brief, Thiobarbituric acid value (TBA) reactive substances (malonaldehyde, other

aldehyde, and volatiles) was distilled from sample homogenate (which adjusted to pH= 1.5 by 4N HCl) in the presence of chelating agents and antioxidants disodium EDTA and propyl gallate. Subsequent reaction with 2-thiobarbituric acid under acidic condition to produce red TBA complexes absorbing at 535 - 538 nm.

Results and Discussion

Chemical characteristics of fat extracted from wheat flour samples infested by *Tribolium confusum*

The chemical characteristics and qualities of the fat extracted from wheat flour samples as affected by infestation with *Tribolium confusum* are shown in Table (2) and Figure (1). From such data it could be noticed that infestation of wheat flour (82 % extraction) with insects induced an appreciable increasing in the total acidity (TA) started with the second week. In the end of infestation periods the total acidity of flour was significant ($p \leq 0.01$) increased by 49.60% compared with 3.13% for the control (uninfested) sample. The present data confirmed that obtained by Nasr (1998). Also, El-Farra *et al*., (1982) found that there was a significant increase in acidity of wheat flour under the non-hermetic storage conditions, as the storage continued especially in the presence of insects and at high moisture content. All of these studies indicated that fat flour subjected to insect's infestation, a chemical reaction takes place resulting in the development of free fatty acids as expressed by increasing in the total acidity. This reaction of the fat with the moisture containing of the wheat flour is known as hydrolysis. The higher degree hydrolysis was noticed in the infested flour with the increasing of the infestation period of time. The Egyptian Standard (ES, 1992) for wheat flour determined this value which should not to be more than 30 mg. According to those data, lipids of wheat flours 82% extraction under the present study becomes rancid as a consequence of oxidation and oxidative rancidity initiated by infestation with insects after 6 weeks of infestation. By other meaning, flour with 6 weeks of insect infestation becomes not identical to the ES, and therefore not suitable for human consumption. The peroxide value (PV) serves as an indicator of the extent of primary oxidation products in the oils. The primary products of lipid oxidation are hydroperoxides which are generally

referred to as peroxides. Therefore, it seems reasonable to determine the concentration of peroxides as a measure of the extent of oxidation. The present data (Table 2 and Figure 1) indicated that infestation of wheat flour with insects induced a significant ($p \leq 0.01$) increasing in PV. In the end of infestation periods the PV of flour was increased by 94.08% compared to 1.75% for the control (uninfested) sample. The opposite direction was recorded for the iodine number (IN). The present data (Table 2 and Figure 1) indicated that infestation of flour with insects induced an appreciable decreasing in IN. In the end of infestation periods the IV of flour was decreased by -11.71 compared to -1.80% for the control (uninfested) sample.

Table (2): Chemical characteristics of fat extracted from wheat flour (82% extraction) infested by *Tribolium confusum*

Infestation period (Week)		Total acidity (TA, mg KOH.100 g^{-1})		Peroxide value (PV, meq.100 g^{-1})		Iodine number (IN, g)	
		Mean ± SD	% of change	Mean ± SD	% of change	Mean ± SD	% of change
Control group	0	23.67 ± 2.01 ^{b}	--------	16.56 ± 0.99 ^{e}	--------	111 ± 1.10 ^{a}	--------
	2	23.99 ±1.12 ^{b}	1.35	16.58 ±0.56 ^{e}	0.12	111 ±0.99 ^{a}	0.00
	4	24.02 ±2.78 ^{b}	1.48	16.81 ±1.25 ^{e}	1.51	111 ±0.58 ^{a}	0.00
	6	24.30 ±1.65 ^{b}	2.66	16.85 ±2.09 ^{e}	1.75	111 ±0.61 ^{a}	-0.90
	8	24.41 ±3.26 ^{b}	3.13	16.85 ±2.51 ^{e}	1.75	110 ±0.91 ^{a}	-1.80
Infested group	2	24.99 ± 2.34 ^{b}	5.58	17.87 ± 1.11 ^{d}	7.91	109 ± 2.2 ^{a}	-1.80
	4	29.56 ± 3.17 ^{ab}	24.88	21.42 ± 2.54 ^{c}	29.35	107 ± 1.6 ^{a}	-3.60
	6	33.53 ± 1.78 ^{a}	41.66	28.78 ± 1.88 ^{b}	73.79	103 ± 0.9 ^{b}	-7.21
	8	35.41 ± 2.11 ^{a}	49.60	32.14 ± 3.05 ^{a}	94.08	98 ± 1.6 ^{b}	-11.71

Means values with the different superscript letters in the same column means significantly different at $p \leq 0.01$

These results implied that fat prepared from wheat flour infested with insects for 6-8 weeks may undergo some degree of polymerization i.e., reduce the number of double bonds when compared with the control samples but more studies needed to demonstrate that. Also, many studies reported that several compounds resulted from fat polymerization may be toxic to animals and result in poor nutrition and growth inhibition (Alexander, 1977; Abd El-Hameed, 2002; Elhassaneen *et al.*, 2003 and Elhassaneen and Sayed, 2015). Bearing in mind such data, it could be noticed that oils characteristics and quality of wheat flour as affected by infestation with insects considered have low values. Consequently, you should pay attention towards the safety of using these flours in human life.

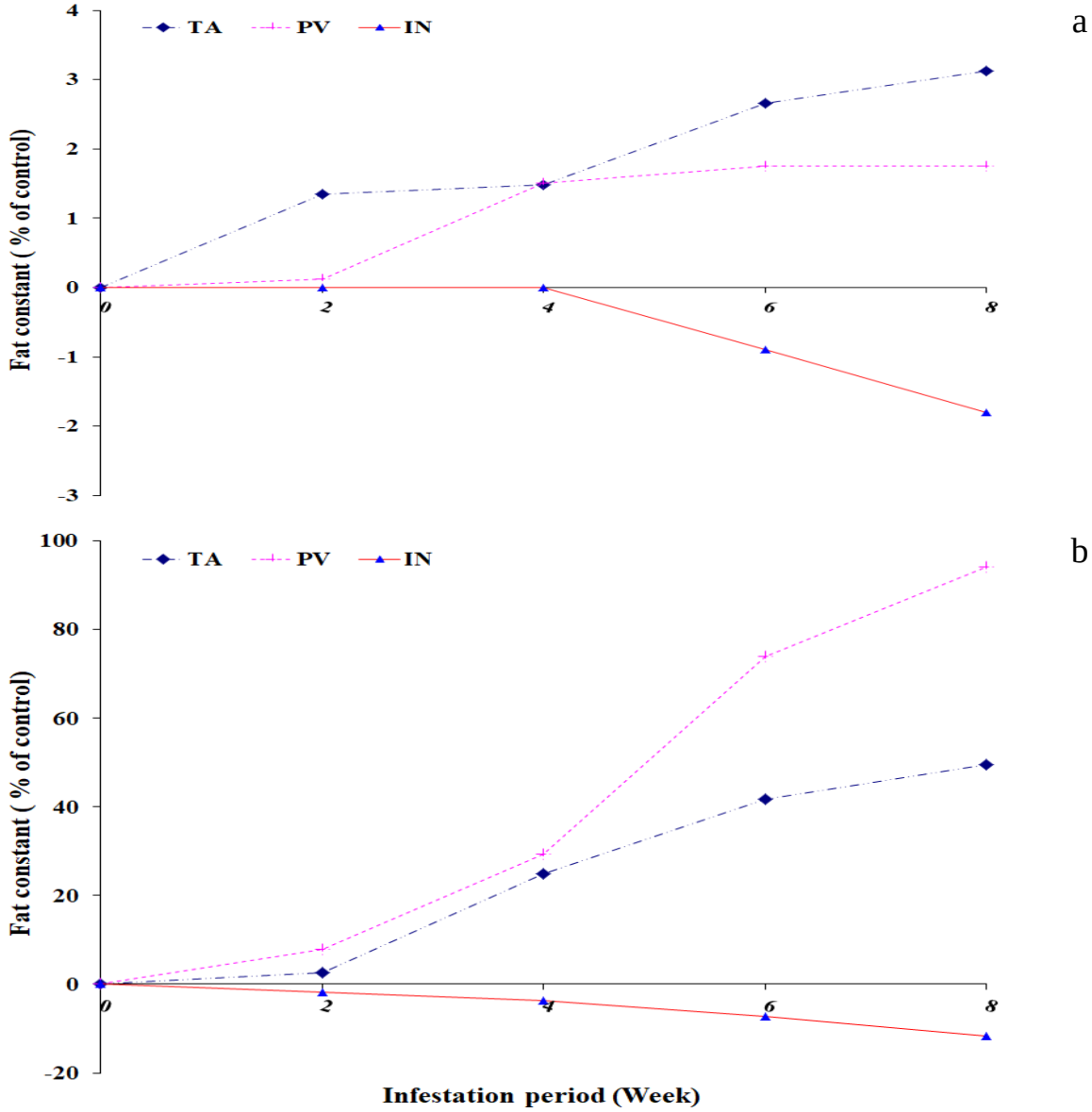

Figure 1. Chemical characteristics of fat extracted from wheat flour (82% extraction) infested by *Tribolium confusum*. a: control group, b: Infested group

Uric acid (UA) and ergosterol (Er) content in wheat flour samples infested by *Tribolium confusum*.

The analysis of the content of uric acid (UA), as excretion of arthropods, is represent one of the most important method available to verify insect infestations in flour (Bijok, 1989 ; Pagani *et al*., 1994 and Abd

El-Hameed, 2002). From the present data (Table 3 and Figure 2) it could be noticed that the infested samples of wheat flour showed UA level higher than the uninfested (control) sample. A relation between the long of infestation period and the UA level is evident. In the end of infestation periods the UA content of flour was significant ($p \leq 0.01$) increased by 308.94% compared to 0.81% for the control (uninfested) sample. These data are confirmed the studies of Galacci, (1983); Wehling *et al*., (1984); Fleurat and Marchegay, (1992); and Pagani *et al*., (1994) who found that the UA levels in wheat flour to be correlated with pest density. The same trend was observed with ergosterol (Er), a steroid involved in some biochemical process in insects and mould metabolite. From such data (Table 3 and Figure 2) it could be noticed that the e Er content in the flour may be related to insect infestation period, even if the levels increase as the infestation period increases. In the end of infestation period, eight weeks, the rates of increasing for this compound was 35.90% compared to 2.56% for the control (uninfested) sample. In a similar study carried out by Pagani *et al*., (1994) reported that the Er content in the flour may be related to insect infestation period, even if the levels increase as the number of insects increases. The increasing of UA levels in wheat flour as the consequence of insects infestation can constitute some concern for the nutritionist. Gout disease was characterized by hyperuricemia, with recurrent attacks of acute arthritic joint inflammation caused by deposition of UA crystal (Gaafar *et al*., 2017). The presence of significant amount of UA in infested wheat flour with insects that introduced by substantial quantities into the bakery products probably represented an indication for the prevalence of gout in the community. But, a lot of studies in the future will be needed to prove that.

Table (3): Uric acid (UA) and ergosterol (Er) content in wheat flour (82% extraction) infested by *Tribolium confusum*

Infestation period (Week)		Uric acid (UA, mg.Kg^{-1})		Ergosterol (Er, mg.Kg^{-1})	
		Mean ± SD	% of change	Mean ± SD	% of change
Control group	0	1.23 ± 0.21 ^{d}	--------	0.39 ± 0.05 ^{b}	--------
	2	1.23 ± 0.22 ^{d}	0.00	0.39 ±0..04 ^{b}	0.00
	4	1.23 ± 0.09 ^{d}	0.00	0.39 ±0.06 ^{b}	0.00
	6	1.24 ± 0.21 ^{d}	0.81	0.39 ±0.04 ^{b}	2.56
	8	1.24 ±0.08 ^{d}	0.81	0.40 ±0.07 ^{b}	2.56
Infested group	2	2.03± 0.19 ^{c}	65.04	0.42 ± 0.19 ^{b}	7.69
	4	3.10 ± 0.57 ^{bc}	152.03	0.57 ± 0.11 ^{a}	46.15
	6	3.99 ± 0.91 ^{b}	224.39	0.56 ± 0.07 ^{a}	43.59
	8	5.03 ± 0.87 ^{a}	308.94	0.53 ± 0.13 ^{a}	35.90

Means values with the different superscript letters in the same column means significantly different at p≤0.01

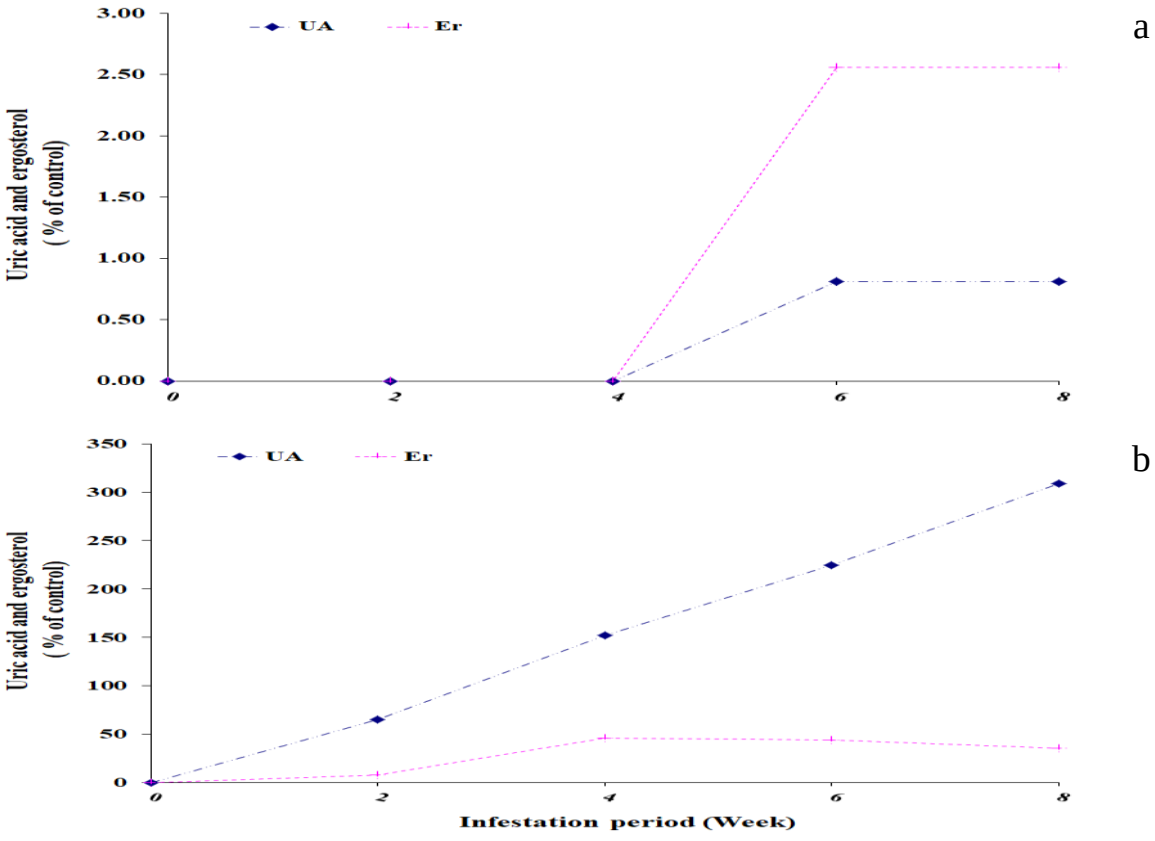

Figure 2. Uric acid (UA) and ergosterol (Er) content in wheat flour (82% extraction) infested by *Tribolium confusum***.** a: control group, b: Infested group

The presence of some toxic/ mutagenic/ carcinogenic compounds on wheat flour infested by *Tribolium confusum*

Several years ago, there is an increasing international concern about the presence and the adverse effects of some toxic compounds in flour as a consequence of infestation with pest insects during storage. Some of these toxic compounds include quinones and malonaldehyde (MDA, product of the oxidation of polyunsaturated fatty acids (Ladisch, 1967; El-Mofty *et al*., 1988, 1989, and 1992; Nasr, 1998 and Abd El-Hameed, 2002). MDA compound represents one of the major products of the oxidation of polyunsaturated fatty acids. Recently, interest in the effect of this compound on human health has been reported by many authors that is mutagenic and carcinogenic (Shamberger *et al*., 1974; Mukia and Goldstein, 1976 and Badawy, 2017). The mutagenicity of MDA has been demonstrated by the Ames salmonella revertant procedure (Shamberger *et al*., 1979) while its carcinogenicity was observed when painted on the skin of mice (Shamberger *et al*., 1974). The present data illustrated in Table (4) and Figure (3) indicated that the level content of MDA in the infested wheat flours was started to increase with the second week of infestation.

Table (4): Malonaldehyde (MDA) and quinones (Qu) content in wheat flour (82% extraction) infested by *Tribolium confusum*

Infestation period (Week)		Malonaldehyde (MDA, mg.Kg^{-1})		Quinones (Qu, mg.Kg^{-1})	
		Mean ± SD	% of change	Mean ± SD	% of change
Control group	0	0.391 ± 0.06 ^{c}	--------	0.49 ± 0.19 ^{b}	--------
	2	0.391 ±0.08 ^{c}	0.00	0.49 ±0.11 ^{b}	0.00
	4	0.393 ±0.01 ^{c}	0.51	0.49 ±0.12 ^{b}	0.00
	6	0.394 ±0.09 ^{c}	0.77	0.49 ±0.09 ^{b}	0.00
	8	0.395 ±0.04 ^{c}	1.02	0.49 ±0.10 ^{b}	2.04
Infested group	2	0.471 ± 0.07 ^{c}	20.46	0.53 ± 0.14 ^{b}	8.16
	4	0.480 ± 0.08 ^{c}	22.76	0.53 ± 0.09 $^{a\,b}$	8.16
	6	1.190 ± 0.12 ^{b}	204.35	0.56 ± 0.08 ^{a}	14.29
	8	1.426 ± 0.23 ^{a}	264.71	0.62 ± 0.13 ^{a}	26.53

Means values with the different superscript letters in the same column means significantly different at p≤0.01

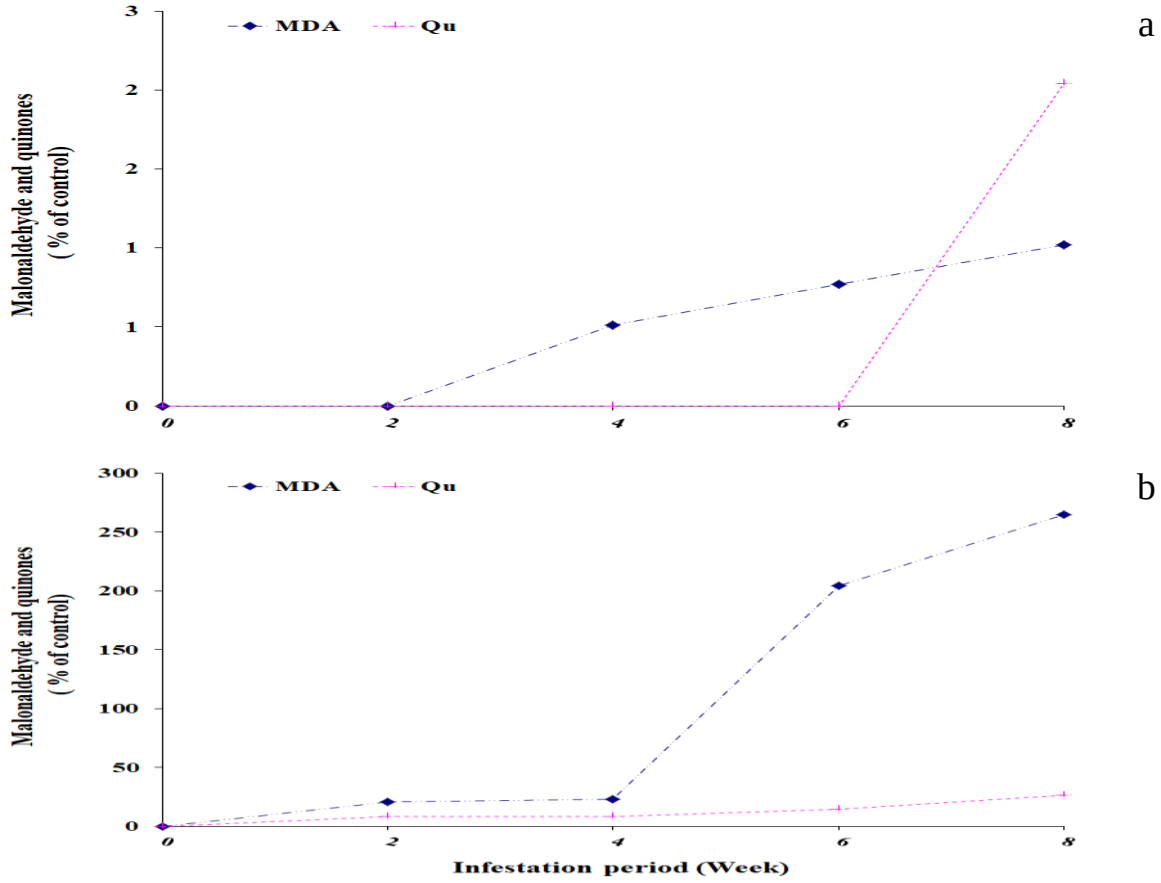

Figure 3. Malonaldehyde (MDA) and quinones (Qu) content in wheat flour (82% extraction) infested by *Tribolium confusum*. a: control group, b: Infested group

In the end of infestation period, eight weeks, the MDA content was significant ($p \leq 0.01$) increased by 264.71% compared to 1.02% for the control (uninfested) sample. The present data confirmed that obtained by Nasr, 1998 and Abd El-Hameed, 2002).

The same trend was observed with quinones (Qu) which have been shown to be carcinogens by extensive experiments *in vivo* and *in vitro* studies (Harvey, 1985; Hawkins *et al*., 1990; Elhassaneen, 1996, Nahed *et al*., 2011; and Judy and Tareisha, 2017). In the end of infestation period, eight weeks, the rates of increasing for this compound significant ($p \leq 0.01$) increased by 26.53% compared to 2.04% for the control (uninfested) sample.The present data in concern with the study of Ladisch, (1967) who reported that the defensive gland of flour beetles were found to secrete a mixture of toxic quinones. Many studies indicated that some of these compounds secreted by the common flour beetles have the ability to induce

carcinogenic and toxicological effects on mammalian body (El-Mofty *et al*., 1988, 1989, and 1992; and Judy and Tareisha, 2017). These authors also indicate that the temperature of the oven in which the biscuits were baked did not alter the carcinogenicity of the infested flour.

Unfortunately, there is no limits concern the allowed level of UA, MDA, Qu and Ur in both fresh and infested wheat flour with insects mentioned in the ES Specifications or the FAO/WHO Codex. Consequently, it is difficult to evaluate the obtained data under the present study. But, the presence of these compounds in such food material used in preparing of bread and bakery products could be considered a hazard to human health.

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إصابة دقيق القمح بخنافس الدقيق (*Tribolium castaneum*) يؤثر على خواصة الكيميائية والسمية وصلاحيته للإستهلاك الآدمى

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المستخلص :

يمثل دقيق القمح أكثر الأغذية أهمية وانتشارا محليا وعالميا بالنسبة للإنسان، إلا أنه في العديد من الدول الأسيوية والإفريقية بما فى ذلك مصر فإنه يتم تخزين كميات كبيرة في مخازن وشون مفتوحة ومعرضة للهواء. وتحت هذه الظروف الغير مناسبة من التخزين فإن الدقيق يكون معرضا للإصابة بالعوامل البيولوجية خاصة الحشرات. لذلك تهدف الدراسة الحالية الى أستكشاف مدى تأثر الخواص الكيميائية والسمية لدقيق القمح المصاب بخنافس الدقيق *Tribolium confusum* وتأثر ذلك على مدى صلاحيته للإستهلاك الآدمى. لذلك تم إعداد 27 عبوة (سعة 1 كيلوجرام للعبوة الواحدة) من دقيق القمح (درجة استخلاص 82%) حيث تم أولا الاحتفاظ بعدد 15 علبة على حالتها لتمثل العينة الضابطة. أما بالنسبة للعينات المعدية (12 عينة) فإنه قد تم وضع 100 يرقة من خنافس الدقيق *Tribolium confusum* فى كل عبوة والتى تم تخزينها فى حضان على درجة 37 درجة مئوية ورطوبة نسبية مقدارها 60% لتمثل العينات المعدية بالحشرات التي سيتم سحبها على فترات تخزينية مختلفة بواقع 4 عبوات كل 2 أسبوع. وفى نهاية كل فترة من فترات العدوى تم نخل عينات الدقيق لإزالة الحشرات وأجزائها من العينات وإعدادها بالطرق المناسبة لكافة التحاليل الكيميائية والسمية.

ولقد أظهرت النتائج المتحصل عليها أن هناك تغيرات كيماوية شملت حدوث زيادة معنوية ($p\leq0.01$) في قيم كل من رقمي الحموضة الكلية والبيروكسيد بنسب 49,60، 94,08% مقارنة بنسب 3,13 ، 1,75% لعينات الدقيق الضابطة أوالغير معدية بالحشرات. كما سجل الرقم اليودى اتجاها معاكسا لما سبق. وعلى الجانب الآخر، أظهرت التحاليل حدوث زيادة معنوية ($p\leq0.01$) في محتوى كل من الكينونات والمالونالدهيد، والتي تعد من المركبات آلتي لها القدرة على إحداث التأثيرات السامة والسرطانية والطفرات، نتيجة للعدوى بالحشرات، حيث زاد المحتوى بنسب 164,71 ، 26,53% مقارنة بنسب 1,02 ، 2,04% لعينات الدقيق الضابطة أوالغير معدية بالحشرات. كما سجل نفس الاتجاه لمركب حامض اليوريك، الذى يعد أحد نواتج الإخراج لمفصليات الأرجل وأحد الأسباب الرئيسية لحدوث مرض النقرس فى الإنسان، والإرجوستيرول الذى ينتمى الى مجموعة مركبات الإستيرويدات التى تشملها عمليات التخليق الحيوى والميتابوليزمى فى الحشرات والفطريات.

وفى النهاية خلصت الدراسة الى أن تعرض دقيق القمح للعدوى الحشرية لفترة 6–8 أسابيع قد أدى الى حدوث تزنخ للدهون نتيجة لعمليات الأكسدة التى أحدثتها تلك العدوى. أيضا فإن تواجد تلك المركبات السامة والمسببة للسرطان والمحدثة للطفرات بنسب محسوسة في دقيق القمح المعدي بالحشرات ، والذي يدخل جزءا كبيرا منه في تصنيع الخبز ومنتجات المخابز، يمكن أن يمثل أحد أكبر الإهتمامات/المخاطر التى تؤثر على صحة المواطنين.

الكلمات المفتاحية: دقيق القمح، العدوى بالحشرات، خنافس الدقيق، خصائص الدهن، حامض اليوريك، المالونالدهيد، الكينونات، الإرجوستيرول.