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Research Article

Function of Ultraviolet Radiation (UV-B) Light on the Survival of Red Flour Beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and their Body Fitness

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Abstract | Red flour beetle, *Tribolium castaneum* (Herbst) is a key insect pest of stored grain. Using radiation is an established method for controlling insect pests in store-grain and a significant stress factor affecting stored grain pests. The Present research work was designed to control *T. castaneum* through ultraviolet radiation (UV-B 313 nm) light is applied at various timings such as 0, 5, 10, 20, 40 and 60 minutes UV-B light on all developmental stages of *T. castaneum*. The results revealed that significant mortality was observed in eggs, larvae and pupal stage at all given timings of UV-B light compared with control. Incubation period of eggs, developmental period of larvae and pupae gradually increased as increasing exposure time of UV-B light. Statistically, no significant difference was observed between 5 minutes UV-light and control group on the incubation period of eggs and larval stages. Significantly, adult longevity of *T. castaneum* was reduced at all given timings of UV-B light as compared to control. However, a significant weight reduction was noticed on larvae, pupae and adult stages from 20, 40 and 60 minutes UV-B light as compared to control. Whereas no statistical difference was observed using 5 and 10 minutes UV-B light as compared with control. Use of UV-B light is a helpful technique for the management of *T. castaneum* because we found that all developmental stages of *T. castaneum* showed susceptibility on UV-B light that may be useful for the protection of stored grain products from *T. castaneum* infestation.

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Introduction

Red flour beetle (*Tribolium castaneum*) (Herbst) (Coleoptera: Tenebrionidae) is the major and a worldwide distribution insect pest in store grain that causes quantitative and qualitative damages to flour by feeding. *T. castaneum* is the most widespread pest in flour mills, warehouses and grocery stores (Garcia *et al*., 2005; Padin *et al*., 2002). Losses of grain estimated that post-harvest grain losses exceed $500 million annually and most of the losses are results of organism source such as insects or mycotoxin (Harein and Meronuck, 1995; FAO, 2013). In developing countries near about 40% of food losses occur at the post-harvest level, which can be attributed to lack of proper storage facilities (FAO, 2011). Hagstrum *et al.* (2013) reported that red flour beetle feed on 233 various commodities such as flour, cracked wheat and wheat bran. According to (Atanasov *et al.*, 1978) single larvae of red flour beetle can attack 88 grains during its life, into leading considerable loss of quality and viability of grain. Infestation caused by red flour beetle in unprotected wheat stored for nine months reduced germination and augmented visually bad seed from 9% to 39% (Karunakaran *et al.*, 2004).

To managed its infestation number of strategies has been used such as chemicals application i.e., methyl bromide and phosphine (Isikber and Oztekin, 2009; Husain *et al.*, 2015), ozone as fumigations, modified atmosphere (Navarro, 2012; Husain *et al.*, 2015, 2017a) organic plant extracts application (Ayvaz and Karaborklu, 2008) and irradiation with UV-C, nonetheless, the difficulty still exists. The above cited chemicals can produce ecological concerns and resistance problems and methyl bromide is approximately banned globally and declared as an ozone layer dangerous fumigant, whereas phosphine need a prolong exposure time to kill the store grain insect's thus increasing resistance (Bouma, 1993; Pimentel *et al.*, 2008). So that reason, the exploration of new alternative so, eco-friendly and cost-effective must be investigation (Singh and Sharma, 2015). Moreover, visible light is dangerous to numerous species of store grains pests (Hori *et al.*, 2014; Ahmed *et al.*, 2021). Therefore, its destruction the organism genetically, physically by disrupting enzyme functions as well as harmfully effects the epidermis and organisms DNA. Low doses of UV-B light can increase the synthesis of Vitamin D in living Organisms (Oonincx *et al.*, 2018) however high doses are dangerous and work as an oxidative stress, which induces hemolysis, that lead to free radicals formation and has lethal affects on living organisms (Jurkiewicz and Buettner, 1994; Afreen *et al.*, 2006). The effects of UV-radiations have been examined against number of store grain insect pests such as *Sitophilus granarius, Alphitobius diaperinus, Tribolium castenium, Tribolium confusium, Cadra cautella, Plodia interpuntella and Collassoburchus maculatous* (Aldryhim and Adam, 1999; Faruki *et al.*, 2005, 2007; Bakr, 2013; Heidari *et al.*, 2016). Present investigate worked focused on using (UV-B, 313 nm) light to the controlling of *T. castaneum*. Influence of radiation varies from species to species and UV type; therefore, might work for few species and might not influence on others species. Numerous research worked has been carried out, while a little information accessible about the influence of UV-B, light on all developmental stages of *T. castaneum*. So, present research was conducted to find out the influence of UV-B light on all developmental stages of *T. castaneum* and this work to augment a useful, cost-effective and eco-friendly management tactic.

Materials and Methods

Insect culture

The experiment was conducted in the Department of Entomology, Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS), Uthal, Balochistan. *T. castaneum* were collected from the surrounding of Uthal godowns and they were cultured in plastic box on wheat flour and reared under laboratory condition at 30±2°C and 60%±10% RH at room temperature.

Collection of developmental stages for UV B-light

Two hundred (200) fresh eggs, Hundred (100) one day old first instar larvae, Fifty (50) one day old pupae and Thirty (30) three day older adults was collected from the insects culture and exposed to different time of period 0, 5, 10, 20, 40 and 60 minutes of UV B-light to observe the hatching (%) of eggs, eggs mortality, eggs incubation period, larval mortality (%), larval periods, pupae mortality (%), pupae period and adults longevity until the end of death. Third larval instars UV treated three days old pupae UV treated and fifteen days old adult UV treated was used for their body weight. Electronic balance Sartorius ED423S was used to find out the insect body weight.

UV-B lights application

All developmental stages of *T. castaneum* exposed to UV-B, 313nm light. The UV-B light was purchased from East-China Electronic Tube Factory, Jiangsu; China. UV-light was subsequently used in cardboard box with the size of (30W × 30L × 30H) for the various time of duration (0, 5, 10, 20, 40 and 60 min). All developmental stages of *T. castaneum* were exposed to UV-B- light on daily basis according to given time of periods. Control of each group was kept under normal light. After the irradiation insects were placed at 30±2°C and 60%±10% RH at room temperature. Each treatment was replicated three times and Experiment designed was used Randomized Complete Design (RCD) under Laboratory condition.

Statistical analysis

The data collected was analyzed with the help of SPSS software and one way Analysis of Variance (ANOVA) was used. The entire means were compared using Tukey Test at p<0.05 value.

Results and Discussion

The maximum incubation period of eggs (6.4±0.25) was recorded on 60 minutes UV-B light followed by 40 minutes (5.3±0.08), 20 minutes, (4.4±0.20), 10 minutes, (4.7±0.15) and 5 minutes (3.7±0.05). At the same time minimum incubation period of eggs (3.4±0.21) was observed in control. Statistically significant difference (p < 0.05) was recorded by 60, 40, 20 and 10 minutes of UV-light irradiation as compared to control, while no significant variation was obersved between control and 5 minutes UV-B light radiation (Table 1).

Table 1: *Influence of UV-B light on egg incubation period of red flour beetle, T. castaneum.*

Treatments (min)	Eggs incubation period (days)
0	3.4±0.21d
5	3.7±0.05d
10	4.7±0.15c
20	4.4±0.20bc
40	5.3±0.08b
60	6.4±0.25a

Values (Mean ± SE) in given Colum letters are significantly difference by Tukey test (P<0.05).

A highest Hatching% of eggs (91.83±0.41) was recorded in the control group followed by 5 minutes (86.66±0.38), 10 minutes, (85.16±0.23), 20 minutes, (84.50±0.34) and 40 minutes UV-B light (79.830.21). The lowest mortality % (77.66±0.18) was recorded in 60 minutes UV-B light. A significant difference (p<0.05) was found among all the given time of UV-B light when it is compared to control group (Table 2).

A longer duration of larvae (35.15±0.52) was observed when it exposed to 60 minute of UV-B light followed by 40 minutes (34.97±0.45), 20 minutes, (30.02±0.22), 10 minutes, (28.51±0.89) and 5 minutes UV-B light (24.40±0.13), whereas, a short duration of larvae (23.35±0.27) was recorded in control. A statistically significantly variation (p<0.05) was found on 60 min, 40 min, 20 min and 10 minutes of UV-B light when it is compared to control group. While, no changes were noticed between control group and 5 minutes UV-light irradiation (Table 3).

Table 2: *Influence of UV-light on the hatching % of eggs of red flour beetle T. castaneum.*

Treatments (min)	Hatching (%)
0	91.83±0.41a
5	86.66±0.38b
10	85.16±0.23b
20	84.50±0.34b
40	79.830.21c
60	77.66±0.18c

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

Table 3: *Effect of UV-Light on larvae development period of red flour beetles T. castaneum.*

Treatments (min)	Larval longevity (days)
0	23.35±0.27c
5	24.40±0.13bc
10	28.51±0.89b
20	30.02±0.22ab
40	34.97±0.45a
60	35.15±0.52a

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

A maximum larval mortality (23.0±0.57) was observed at 60 minutes of UV-B light followed by 40 minutes (22.66±1.20), 20 minutes, (17.33±0.20), 10 minutes, (12.33±0.15) and 5 minutes UV-Lights (9.66±0.12), whereas a minimum larvae mortality (5.33±0.73) was recorded in the control. A significant difference (p<0.05) was noticed between the control group and all other respective timings of UV-B light (Table 4).

Table 4: *Effect of UV-B light on larval mortality (%) of red flour beetles T. castaneum.*

Treatments (min)	Larval mortality (%)
0	5.33±0.73e
5	9.66±0.12cd
10	12.33±0.15c
20	17.33±0.20b
40	22.66±1.20a
60	23.0±0.57a

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

A maximum pupal period (23.6±0.10) were observed in 60 minutes of UV-B light followed by 40 minutes (19.3±0.30), 20 minutes, (15.9±0.13), 10 minutes, (15.1±0.23) and 5 minutes UV-B light (14.2±0.51), while a minimum pupal period (11.5±0.78) was recorded on the control. A significant difference (p<0.05) was found between control and all given time of UV-B light (Table 5).

Table 5: *Effect of UV-B Light on pupal period of red flour beetle T. castaneum.*

Treatments (min)	Pupae period (days)
0	11.5±0.78d
5	14.2±0.51c
10	15.1±0.23dc
20	15.9±0.13dc
40	19.3±0.30b
60	23.6±0.10a

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

A maximum Pupal mortality (27.33±0.95) was observed on 60 minutes of UV-B light followed by 40 minutes (22.33±1.33), 20 minutes, (18.66±0.67), 10 minutes, (13.6±1.07) and 5 minutes UV-B light (10.0±0.88), while a minimum pupal days (6.6±0.87) was recorded on the control. A significant difference (p<0.05) was found between control and all given time of UV-B light irradiation (Table 6).

Table 6: *Influence of UV-light on pupal mortality (%) of red flour beetle T. castaneum.*

Treatments (min)	Pupae mortality (%)
0	6.6±0.87f
5	10.0±0.88e
10	13.6±1.07de
20	18.66±0.67c
40	22.33±1.33b
60	27.33±0.95a

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

The most prolonged adult's longevity (74.85±0.27) was recorded in the control group followed by 5 minutes (68.41±0.91), 10 minutes (65.52±0.17), 20minutes, (63.59±1.01) and 40 minutes, (54.04±0.63), while a shortest adult's longevity (47.42±0.47) was recorded in 60 minutes. A statistically significant (p<0.05) difference was observed among all the given time of UV-B light irradiation when it was compared with the control group (Table 7).

Table 7: *Influence of UV-B light on the longevity of adults of red flour beetles T. castaneum.*

Light exposure (min)	Adults longevity (days)
0	74.85±0.27a
5	68.41±0.91b
10	65.52±0.17c
20	63.59±1.01c
40	54.04±0.63d
60	47.42±0.47e

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

Maximum larvae weight (1.30±0.13) was recorded in the control group followed by 5 minutes (1.16±0.03), 10 minutes, (1.10±0.17), 20 minutes, (0.76±0.23) and 40 minutes UV-B light (0.68±0.12). While a minimum larvae weight (0.65±0.17) was recorded on 60 minutes. A statically significant difference (p<0.05) was founded by 60-, 40- and 20-minutes UV-B light as compared with control group (Table 8).

Table 8: *Influence of UV-light on the larval weight of red flour beetle T. castaneum.*

Treatments	Larval weight (mg)
0	1.30±0.13a
5	1.16±0.03a
10	1.10±0.17a
20	0.76±0.23b
40	0.68±0.12b
60	0.65±0.17b

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

Maximum pupal weight of red flour beetle (2.31±0.13) was recorded in the control group followed by 5 minutes (2.22±0.32), 10 minutes, (2.17±0.53), 20 minutes, (2.09±0.41) and 40 minutes UV-B light (1.98±0.12). Although minimum pupal weight (1.87±0.21) was recorded on 60 minutes UV-B light. Statistically significant difference (p<0.05) was recorded at 60 and 40 minutes UV-B light as compared with the control, whereas no significant changes were seen in control, 5, 10, and 20 minutes UV-B light (Table 9).

Maximum adult's weight of red flour beetle (1.83±0.23) was recorded in the control group followed by 5 minutes (1.79±1.06), 10 minutes, (1.73±1.15), 20 minutes, (1.60±0.98) and 40 minutes

UV-B light (1.45±0.83). Although minimum adult's weight, (1.31±0.93) was recorded in 60 minutes UV-B light. Statistically significant difference (p<0.05) was recorded by 20,40 and 60 minutes UV-B light as compared with control, whereas no significant difference were seen in control, 5 and 10 minutes UV-B light (Table 10).

Table 9: *Influence of UV-light on the pupal weight of red flour beetle T. castaneum.*

Treatments	Pupae weight (mg)
0	2.31±0.13a
5	2.22±0.32a
10	2.17±0.53a
20	2.09±0.41ab
40	1.98±0.12b
60	1.87±0.21b

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

Table 10: *Influence of UV-light on the adult's weight of red flour beetle T. castaneum.*

Treatments	Adult weight (mg)
0	1.83±0.23a
5	1.79±1.06a
10	1.73±1.15ab
20	1.60±0.98b
40	1.45±0.83bc
60	1.39±0.93c

Values (Mean ± SE) in given column letters are significantly difference by Tukey test (P<0.05).

Ultraviolet radiation has a strong potential to have an effect on the physiology of insects pest. In current experiment we examined the contact of UV-B light on the developmental stages of red flour beetle *T. castaneum* and their body weight. In the present results found the incubation period of *T. castaneum* eggs prolonged after 10 minutes of exposure to UV-B radiation as compared with control group. Similar findings also were noticed by (Faruki *et al*., 2007) it was reported that eggs of the almond moth, red flour beetle and confused flour beetle took long times for hatching on different time of UV-C light. Further these results are supporting with the results of (Sorungbe *et al*., 2016) also found the delay of hatching % of eggs *C. cautella* on UV-C radiation. Yang and Sacher (1969) irradiated red flour beetle eggs of different ages with X-rays to find out the influence of doses on age of hatching. They reported a delay in the development that was part of the irradiation doses. The relationship of delay in development with respect to the dose was linear at all stages. Hatching % of eggs *T. castaneum* significantly reduced as time of UV-B light increased in contrast with control group. The results of present study are supporting the resulting of (Sorungbe *et al*., 2016; Alwaneen *et al*., 2019) who noticed the eggs of *C. cautella* are remarkable sensitive on ultraviolet radiations. Faruki *et al*. (2007), Bakr (2013) moreover made known in the minimization in the rate of hatching percentage of eggs, *T. castaneum, C. cautella, T. confusum* and *Tyrophagus putrescentiae* mites on UV-C and UV-B light. Faruki *et al*. (2005) reported that the reproduction of lesser meal worm eggs resulting from UV irradiated second and third instars larvae were decreased accordingly. An extremely susceptible egg of Indian meal moth, wax moth, and large weed bug and worker termites with UV- radiation was observed by (Beard, 1972). Quraishi and Matin (1963) recommended that the sensitivity of eggs of *Callosobruchus chinensis* to radioisotope differed at their various developmental stages. It was also noticed from Hassan and Khan (1998) that there is potency in the eggs of Uzi fly developmental from UV irradiated pupae. Guerra and Shaver (1969) examined that when eggs of tobacco bud worm and corn ear worm released on UV-light with short wavelength the hatching percentage of eggs slowly reduced with enhancing time of UV-light. UV- spoils the cellular components, for example lipid membrane, protein and nucleic acids, as well was induce various chemical compounds. Few basic facts recommend that embryonic growth is very much susceptible to stress. When UV-light join to the eggs chorion, it damaged DNA, as in the *T. granarium* in which UV-C light spoiled the eggs chorion there by resulting in the eggs inner contents leakage (Ghanem and Shamma, 2007; Zhao *et al*., 2007).

Larval and pupal mortality significantly increased on all given treatments of UV-B light as contrast to control group. Same outcome also was found by (Faruki *et al*., 2005; Pandir and Guven, 2014; Guven *et al*., 2015; Ali *et al*., 2016) they reported that larval and pupal mortality was totally related with irradiation doses. Insects mortality ratio enhance with rising UV-B light time. After exposed larvae on UV-B light larvae was found immobile, stopped their development, and have a dark black body color upon death, showing signs that was same to the sunburns in human due to solar (Rajpurohit and Schmidt, 2019). A significantly declined adult's emergence from irradiated pupae was found by (Hassan and Khan, 1998; Faruki *et al*., 2007; Ali *et al*., 2016). The reason behind this is that pupae stage is not moveable and VU-radiation directly enter and disturbs important physiologically processes (Tilton and Brower, 1983).

Exposure of UV-light cause stress to *Helicoverpa armigera* (Meng *et al*., 2009, 2010) and decrease the damaging impact an organism may extend its growth stages periods (Ali *et al*., 2016). The present experimental data were showing when larvae were showed to UV-B lights their developmental time significantly increased in contrast with control group. Such prolonged growth time can be a tactic for suppressing the impact of stress in upcoming generations. Numbers of studies reported that early instars of insects are more susceptible as compared to mature insects on UV radiations directly and indirectly by (Watters, 1976; Tilton and Brower, 1983; Shayesteh and Barthakur, 1996; Zhao *et al*., 2007) and also it is examined that the effects of UV radiation on living organisms is allied to the growth of cells. Ultraviolet light can be used as an environmental stress factor in insects (Meng *et al*., 2009, 2010). There are number of insects has the capability to extend their growth stages to avoid themselves from harsh consequence of ecological circumstance for their survival, which is the plane of organisms to adjust themselves to the ecological situation to protect themselves from harmful effects on their developmental stages (Gintenreiter *et al*., 1993; Van Ooik *et al*., 2007).

Meng *et al*. (2009), Ali *et al*. (2017) studied that the UV-radiation stimulates oxidative stress in adult stage of insects. This kind of irradiation can disturb the normal working capability of proteins and also increases the resultant products of protein oxidation of adult stage of *T. castaneum*. The above-mentioned processes reduced adult life span and enhanced the reproduction (Ali *et al*., 2016). Same results were also observed in the present study in present study we noticed that the adult life span of *T. castaneum* significantly reduced when it exposed to all given time of UV-B light as compared with control group. In the light of life history theory, a trade of many survival occurs when both characters are very costly (Zera and Denno, 1997; Zera and Harshman, 2001). Moreover, generally biological theory forecast that the breeding of an organism has a survival cost (Williams, 1966; Roff, 1992). Ali *et al*. (2016) examined that the oxidative stress influence physiological cost of reproduction and act as driving force badly affecting on life period. Reduction of adult's longevity on UV-B radiation could be owing to the enhanced cost of antioxidant defenses. Insects have the capability to protect themselves against the harsh influence of UV lights and this reaction is considered to be expensive in terms of energy, surely there is a fitness cost for this protection (Meng *et al*., 2009). The theoretical history of life shows that the capability of living of an organism may reduce under given circumstance (Holloway *et al*., 1990; De Jong and Van Noordwijk, 1992). In present examine reduction of adult life span of *T. castaneum* might be the cause of increased oxidative stress after exposed to UV-B radiation.

According to (Faruki *et al*., 2005) longer exposure of Ultraviolet radiation, reduce the body weight of all the mature and immature stages of *A. diaperinus* (Panzer). Similar results also was found in our results we noticed that a significant reduction of Larvae, pupae and adult weight of *T. castaneum* was found at longer exposure time 60, 40 and 20 minutes of UV-B radiation as compared with control. No significant, difference was observed among 5 and 10 minutes UV-light with control among all of stages. The above observation indicates that the epidermis of radiated larvae was injured rapidly, which reduce development, causes nutrient stress due to the irradiated larvae remained stunted, it is possible that they stopped feeding and this possibility is also supported from the reality that in natural ecosystem UV-B radiation reduce the feeding of herbivorous insects (Mazza *et al*., 1999). Size of any animal body is determined by the time of the developmental period and the quantity of nutrients gained during the same period (Davidowitz *et al*., 2004). In current research it is noticed that UV-B light delay metamorphoses and boost the developmental period but the reduction of pupae weight also indicates that the insects either decrease their nutrient intake or enhanced their nutrients consumption, that might be connected to a decline in feeding activity or to get huge energy inputs for repairing activities.

Conclusions and Recommendations

In present experiment we examined the influence of UV-B radiation on all developmental stages of *T. castaneum* on different time periods. Significant increase mortality of eggs, larvae and pupae was found on all given timings of UV-B radiation as contrast to control. UV-B radiation reduced adult longevity and increased immature development period such as incubation period of eggs, larval and pupal days. Moreover, UV-B radiation disturbs the fitness of larvae, pupae and adults in the form of weight. Present research revealed that use of UV-B radiation can suppress the population of *T. castaneum* at all developmental stages. *T. castaneum* is a key insect pest of stored grain products and it completes all developmental stages within food products. The provision of UV environment to red flour beetle makes it extremely susceptible to ultraviolet radiation. Therefore, the observed changes in the influence of UV-B light on developmental and metamorphosis might be correlated to the species and developmental stages. UV-B light stimulates high mortality in various developmental stages such as eggs, larvae and pupae under increased doses of UV-B light. The results revealed that there was reduction in percentage of eggs and emergence percentage of adults caused by UV-B light in the tested insect pests. The mortality of larvae of *T. castaneum* increased and decreased longevity of adults was also caused by UV-B light which indicates that use of UV-B light is promising to control insect pests of stored grains. It may be concluded that use of radiation is very harmless and hygienic method for food preservation and pest control. The present research will be helpful for the extension workers, researchers, store keepers, warehouse keepers and also can contribute for the better understanding of the effects of UV-B light on signaling insect's mechanisms in insect's metamorphosis.

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Novelty Statement

Present research is reported for the first time in Pakistan in which UV-B 313nm light has been used on all developmental stages of Red Flour Beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and it's Body Fitness.

Author's Contribution

Moheem Khan: Conducted research.
Arif Ali: Designed experiment.
Shafique Ahmed Memon: Worked on plagiarism.
Taimoor Khan Qambrani and Ghulam Khaliq: Reviewed the article.
Jahanzaib Khan and Saghir Ahmed: Analyzed data.
Azmat Hussain Abro and Sohail Azeem Baloch: Formatted the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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