Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

A Review of X-Ray for Detection of Insect Infestation in Fruits and Vegetables

S.Khan[1]*, Z.Xiaobo[1], M.Irfan[2],R.D.Khan[3], K.Ur.Rahman[3], H.Akbar[3],M.Jamil[2], M.Ilyas[4], Irshad khan[4], AbidRahim[4],TayyabaMuhtar[4],Z.Zafar[5],and Z.Ur.Rahman[6]

[1]School of Food and Biological Engineering, Jiangsu University, Jiangsu Zhenjiang 212013, china
[2]Industrial Biotechnology Divisions, National Institute for Biotechnology and Genetic Engineering, Faisalabad, Pakistan
[3]Department of Biotechnology, Abdul Wali Khan University Mardan, kp, Pakistan
[4]Department of Biotechnology University of Malakand,kpk,pakistan
[5]Soil and Environmental Biotechnology Division, National Institute for Biotechnology and Genetic Engineering, Faisalabad, Pakistan
[6]Cardiology Unit Leady Reading Hospital (L.R.H) Peshawar Kp, Pakistan
Corresponding author: Sulimanbiotech315@gmail.com

ABSTRACT

Insect damage in fruits and vegetables cause major production and economic losses in the agriculture and food industry worldwide. Monitoring of internal quality and detection of insect infestation in fruits and vegetables is critical for sustainable agriculture. Early detection of an infestation in fruits can facilitate the control of insects and the quarantine operations through proper post-harvest management strategies and can improve productivity. The present review recognizes the need for developing a rapid, cost-effective, and reliable insect infestation monitoring system that would lead to advancements in agriculture and food industry. In this paper, an overview of x-ray detection insect damages in fruits and vegetables was presented and applications were discussed. Also, the main challenges and limitations of x-ray detection methods in the agricultural products quality assessment were also elucidated.

Keywords: Food Infestation**;**Insect Infestation**;**Fruit fly**;** X-ray

Introduction

Enormous quantity of fruits and vegetables are infested with insects each year, causing major production and economic losses in agricultural and food industry worldwide. The presence of insect pests in horticultural commodities leads to major disruptions in the storage, processing and shipment of these products. For example, it has been estimated that fruit flies damages could cause annual economic losses of more than $42 million in Africa and $1 billion worldwide, and an infestation of a particular type of fruit fly (Ceratitiscapitata) in the U.S could cost as much as $1.5 billion yearly due to export sanctions, lost markets, treatment costs and crop losses Kendra et al. (2011)U.S. appropriations for exotic fruit flies risk management programs are over $57 million per year (USDA-APHIS 2010). In fact, the loss of post-harvest fruits and vegetables in circulation is huge reaching 30%~40% every year (Gao et al. 2010; Lixin et al. 2004) and thus much attention should be paid to the post-harvest processing technology.

In many countries, zero tolerance regulations for the presence of insect infestation in fruits impose high strains on the food industries by making their entire shipment unmarketable just for the

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

presence of a few infested fruits in a shipment. It is, therefore, important to identify fruits with insect damage before they are shipped to the market.

On the other hand, traditional sorting techniques, including manual sorting, are generally inadequate for the detection and removal of fruits with hidden internal damages. Gould, Abee, Granum, and Jones (1995) estimated that only about 35% of grapefruits infected with Anastrephasuspensa were detected by trained inspectors. Consequently, development of methods which will increase the probability of detection of infestation in imported material is therefore highly sought after. Insect feeding damages often occur within fruits and vegetables without showing an obvious external symptom until it is nearly fullymature/ripen. In most cases, adult females have well-developed ovipositors that insert eggs beneath the skin of host fruits and vegetables. Then, the eggs hatch into larvae which feed on the decaying flesh of the fruit. While some infected samples can be identified by visual inspection based on the presence of external pest marks, such as holes or punctures, there are cases in which no visible external marks or holes are present for the damaged fruits. As a result, noninvasive methods of detection are needed to monitor the internal quality of fruits. With the rapid development of technology and computer science application in the agricultural field, new methods of non-destructive detection of insect infestation of fruits and vegetables have emerged. A variety of techniques such asnuclear magnetic resonance (NMR) is fast, precise and non-invasive equipment that is usually used to identify food quality, mainly for fruits, vegetables, meat and aquatic products (S Khan et al., 2021).

There is currently no reference paper reviewing and collating the state-of-the-art based on previous research and current works being done in the non-destructive detection of insect infestation in fruits and vegetables. Thus, in this present paper also summarized X-ray's used as a non-destructive detection of internal insect infestation in fruits and vegetables are reviewed and as well as their limitation.

Insect Infestation in Fruits

Insect infestations in fruits are complex as infestations may not be visible outside and cannot be easily identified manually. The insect eggs develop from the flowering stage and mostly develop inside the fruit's seed. The infestation may later on lead to progressive damage to the fruits. Quarantine of agricultural products requires inspection of each and every fruit. The feasibility to identify insects in mango, apple, peach, guava, and olives has been reported by different groups (Jackson & Haff, 2006);. The infestation of fruits by oriental fruit fly was identified manually after 2–3 days of egg implantation inside the fruits whereas the infestation was very obvious from the X-ray images only after 6 days of infestation. Mango seed weevil is a serious pest, and identification will improve the reliability of export market and processing industries. Correct identification of all weevil damages in mangoes has been reported. It was determined that sometimes surface damages in olives may be mistaken for insect infestations, but X-ray images revealed the internal structures clearly (Jackson & Haff, 2006). It was determined that the visual inspection of X-ray images can detect even small damages. The automatic machine recognition algorithm needs to be improved to increase the detection percentage and to reduce the false positives.

Olives

Bactroceraoleae (olive fruit fly) is the main insect pest of olives worldwide (Daane & Johnson, 2010) and a frequent cause of reduced olive oil quality. The first discovery of the olive fruit fly in

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

California occurred in 1998 and it now poses a significant threat to commercial olive growers throughout the state. California table fruit processors have zero tolerance for olive fruit fly damage, and the presence of even a few infested fruits can lead to rejection of an entire lot.Transgenic crops is one of the most common application in biotechnology to decrease insecticides uses as well as increased yields of different crops(Suliman Khan et al.)

Since not all olives in an infested lot are infested, an excellent product could be recovered if good product could be separate from defective product. Traditionally, research on the olive fruit fly has focused on control strategies including monitoring, trapping, sanitation, bait sprays, and biological controls (Zalom, Peng, Toscano, & Hummel, 2003). Until recently, no research was reported on detection and removal of insect damaged fruit from the processing stream. This has changed; however, with Moscetti et al. (2015) demonstrating the feasibility of detecting infested olives using NIR spectroscopy to determine a small number of wavebands with discriminating power. Generally, infested fruit has a small hole on the surface at the point of exit, suggesting machine vision as a potential means of detection. However, preliminary attempts have shown this to be unreliable because other kinds of surface damage leave similar marks that are difficult to distinguish from insect damage. While the markings on the surface are similar, the interiors are not. The olive with the exit hole shows extensive damage due to tunneling, while the non-infested olive shows negligible interior damage. Thus, surface imaging is not a reliable technique for detection of infestations.

Apples

One of the most promising ways to reduce chemical use is breeding cultivars which are resistant or tolerant to pests and diseases. This approach has already had significant success. There are now several new apple cultivars which are resistant to economically important diseases such as apple scab and powdery mildew (Pedersen et al. 1994; Nakov et al., 1999). There has been less progress in developing cultivars resistant to insect and arthropod pests, though intensive research has been carried out, especially on cultivars resistant to sucking pests such as aphids and mites (Habekuss et al., 2000).

The internal structure of pomes and drupes are not complex, and the internal density of both fruits is evenly distributed except for the area near the core. Therefore, any internal injuries of these fruit could be clearly revealed by X-ray imaging. Figure 1 is an X-ray image of an apple into which Oriental fruit fly eggs had been implanted for 7 days, and this is the earliest time the internal injury of the apple could be detected by either X-ray image or dissection. No surface injury was observed (Fig. 1A). A tunnel created by the fly larva was detected by X-ray imaging (Fig. 1B), and it exactly matched the internal injury found when the apple was subsequently dissected (Fig. 1C)(Yang et al., 2006).

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

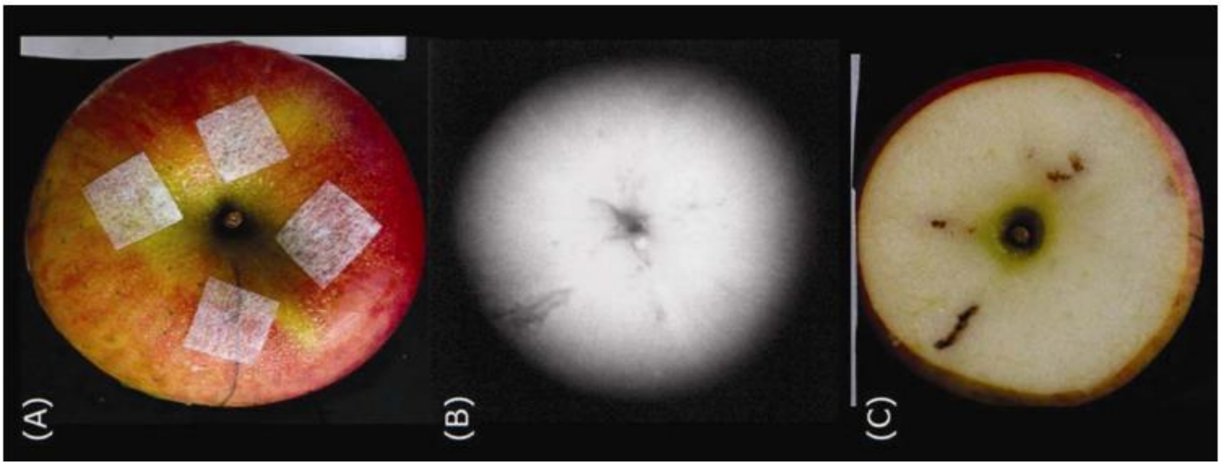


Fig.1. Seven days after Oriental fruit fly eggs were implanted, an apple showed no outer damage (A) while an X-ray image (B) revealed signs of tunnels which closely matched the internal injuries (C). The four white patches in (A) are surgical tapes used to cover the pin-holes after egg implantation(Yang et al., 2006).

Pears

THE APPLE MAGGOT, Rhagoletispomonella (Walsh), and the blueberry maggot, Rhagoletismendax Curran, are among the most important late-season pests of apples, Malusdomestica L., and highbush blueberries, Vacciniumcorymbosum L., respectively, in the United States and Canada (Bush 1966, Howitt 1993). Infestation of the crop by these frugivores renders it unmarketable in regions with quarantine restrictions for R. mendaxandR. pomonella. Fruit destined for regions certiÞed as being free of these pests is inspected and detection of one infested fruit leads to rejection of the entire load. Currently, organophosphates such as phosmet, malathion, and azinphosmethyl are the most widely used insecticides in apples and blueberries for control of Rhagoletis fruit ßies (Wise et al. 2003).

Figure 2 shows two pears which were infested by Oriental fruit fly larvae; one had eggs implanted for 3 days (Fig. 2A, C, E) and the other for 6 days (Fig. 2B, D, F). The X-ray images revealed internal injuries as early as 3 days after egg implantation into the pears. The red arrows in Fig. 2A, E indicate slight injury detected by the X-ray image, and the contour analysis of the density changes showed uneven contour lines in this area (Fig. 3A & C) while those of the healthy part were smooth. In the pear infested for 6 days, the internal injuries were more serious than those of the pear infested for 3 days, and many tunnels were easily detected on the X-ray image (Fig. 2B). The contour lines of the serious internal injuries are not continuous (Fig. 3B, D), which greatly differs from the smoother lines shown in Fig. 3A, C. The best intensity condition for X-ray photography of the apple and pear was 45 kVp.(Yang et al., 2006)

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

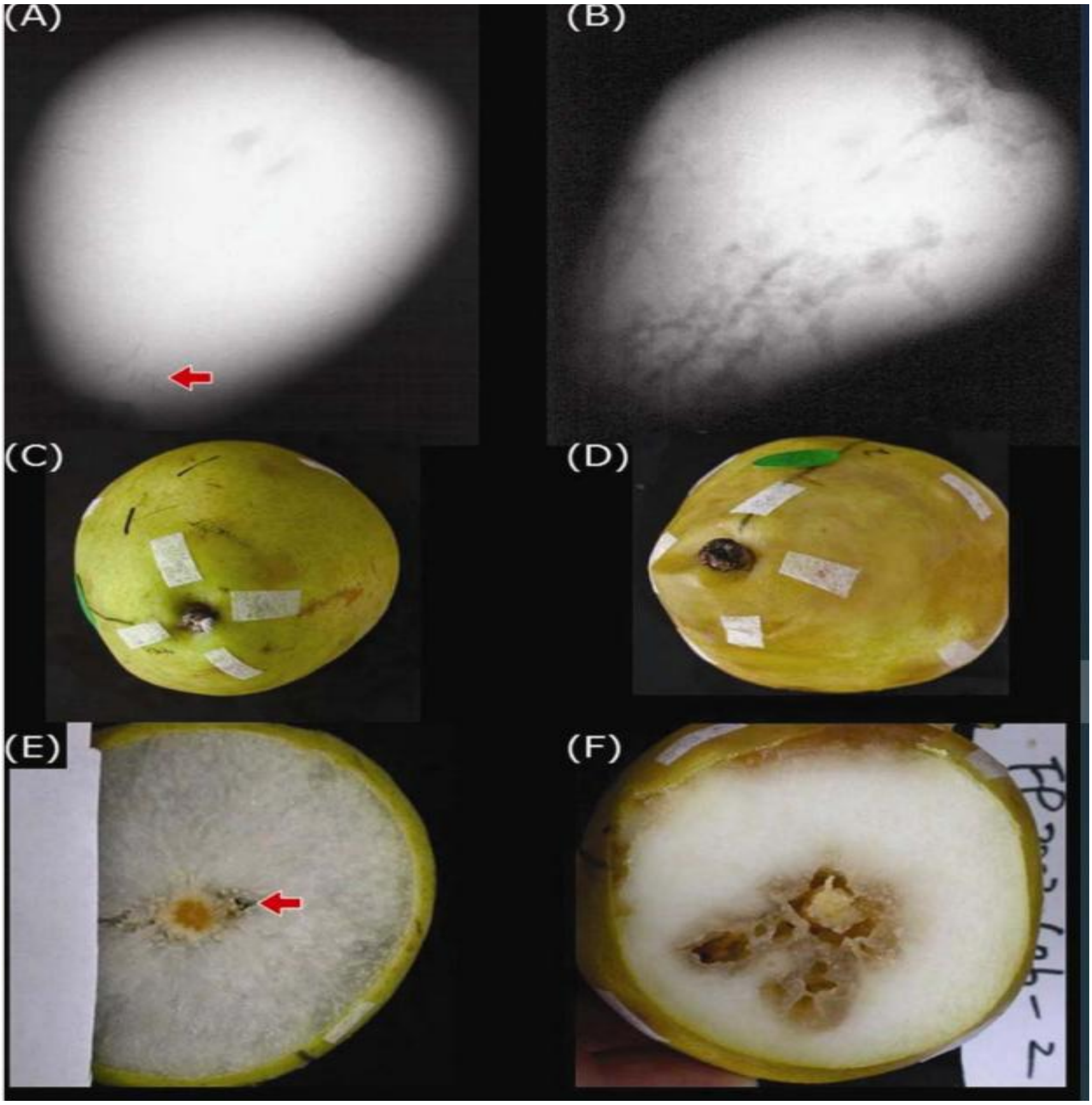


Fig.2. Images of pears at different times of infestation. Three days after eggs were implanted, X-ray images (A) successfully revealed subtle signs of injury (red arrow) which were not detectable from the surface (C) and which closely matched the internal injuries (E). More-obvious signs of injury shown as tunnels in the X-ray image (B) were found 6 days after egg implantation, and serious internal injuries could be seen (F), while no obvious outer damage was revealed (D) (Yang et al., 2006).

Nuts

A potential carcinogen is determined to be present in the nuts (almonds, pistachios, etc.) with split hulls before harvest and in insect-infested nuts (Kim & Schatzki, 2001). Standard grades restrict the presence of insect damages to 1–3 % by weight in pistachio nuts during grading. Suspected pistachio nuts removed by visual inspection by humans at the end of processing stream are reported to contain 89 ng of aflatoxin/g of nuts where the permissible level is only 4 ng/g for US No:1 grade (Casasent, Sipe, Schatzki, Keagy, & Le, 1996). Infested almonds were identified with 81 % accuracy when images from X-ray films scanned at a resolution of 0.17 mm2/pixel were analyzed using image

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

processing algorithms. The identification accuracy dropped to 65 % when real-time images recorded with sensor resolution of 0.5 mm2/pixel were analyzed (Kim & Schatzki, 2001). The false positives also increased to 9 % as compared to 1 % with radiographic images. The algorithm is fast enough to inspect 66 nuts/s but to implement this technique in industry; a high-resolution X-ray sensor is required. Different identification percentages (83–90 %) were obtained when the histogram features and moments of the raw and edge-enhanced images of the pistachio nuts were used as features (P. M. Keagy, Parvin, & Schatzki, 1995). Variability in a human inspection system was demonstrated by the recognition levels of six subjects ranging from 83.1 to 91.7 % in analyzing the X-ray images of pistachio nuts (Casasent et al., 1996), but the classification accuracy was better than the machine recognition. The low recognition by the machine might be due to low resolution of the X-ray images used during analysis (radiographs scanned at a resolution of 0.173 mm2/pixel were converted to images with 0.5 mm2/pixel resolution to match the available sensors). Pecans and chestnuts have hard shells and hence are difficult to inspect the quality of nuts visually. The use of X-ray imaging system to determine the nut weight and insect damages in pecan nuts is demonstrated by incorporating nut meal of different weights and insect damages into pecan nut shells that were cut open and glued together before imaging. It was determined that the nutmeat weights determined from the X-ray images was within an error of 10 % and insect damages were only visible after improving the contrast of the X-ray images due to the uneven meat nature of pecan nuts(Kim & Schatzki, 2001).

Insect Infestations in Grain

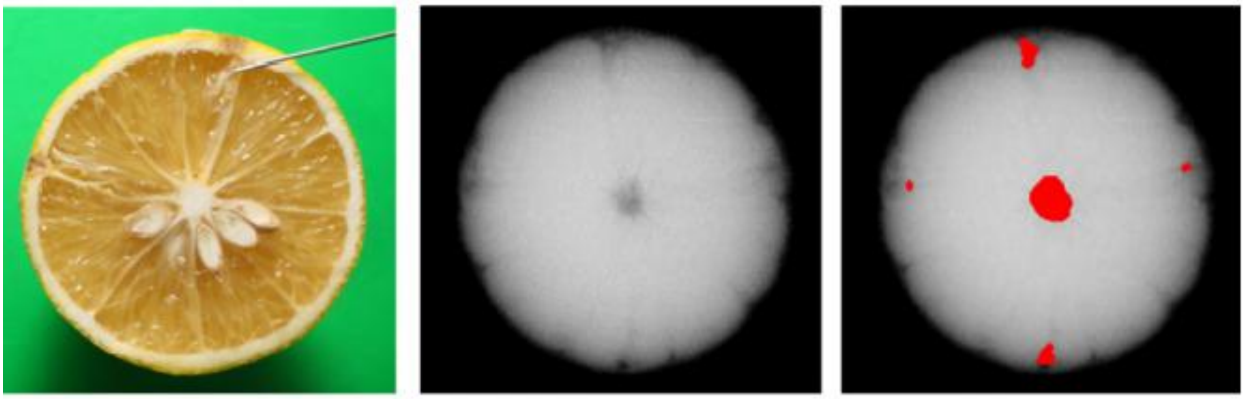
The use of X-ray technique to detect infestations in grain gained momentum in 1926 as it is considered an efficient method in detecting infestation due to borers in grain. X-rays were then used to detect internal insect infestations in cotton seeds (Fenton & Waite, 1932). Presence of pink bollworms in cotton seeds can be detected by examining X-ray images of a single layer of cotton seeds with a hand lens. Imperfect and infested seeds are not distinguished easily, but experience in examining the films increases a person’s ability to see the difference. Soft X-rays have been used in several studies to detect internal insect infestations in seeds and cereal grains by manually analyzing X-ray radiographs (R. Haff & Slaughter, 2004). Use of X-rays to detect infestations due to Sitophilusoryzae (L.), Sitophilusgranarius, and Sitotrogacerealellain wheat; S. oryzae and S. cerealella in corn; S. oryzae in rough and milled rice; Acanthoscelidesobtectus (Say) and Callosobruchusmaculatus (F.) in cowpeas; and A. obtectus in pinto beans and kidney beans; Sitophiluszeamais, S. oryzae, S. cerella, and Rhyzoperthadominica (F.) in wheat and corn is demonstrated by different researchers (Karunakaran, Jayas, & White, 2002). Infestations caused by Cryptolestesferrugineus (Stephens) and Triboliumcastaneum larvae were correctly identified with more than 81 % accuracy; more than 97 % of kernels infested by Plodiainterpunctella, S. oryzae, and R. dominica larvae were correctly identified; and all kernels infested by S. oryzae, and R. dominica pupae-adults were correctly identified(Karunakaran, Jayas, & White, 2004). Among different methods used to detect insect infestations in grain, soft X-ray method is recognized as the simple and fast method to detect hidden insects in grain (Schatzki, Wilson, Kitto, Behrens, & Heller, 1993). X-ray method is extensively (40 % in the US mills) used to determine insect infestations and has been determined that X-ray images can reveal even the insect plugs in grain kernels. (P. Keagy & Schatzki, 1991) determined the effect of image resolution to detect infested grain kernels. The X-ray radiographs were scanned and digitized at different resolutions of 32.8, 65.6, 131.2, and 262.4 μm

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

per pixel, and the recognition levels by trained persons were recorded. Best recognition level was achieved when the image resolution was 65.6 µm of film per pixel. Therefore, for real-time recording of X-ray images, the sensors in the X-ray detection system should not be larger than 65.6 µm in size(P. Keagy & Schatzki, 1991.

Orange

The trunk borer, Anoplophoraversteegi, Citrus psylla, Diaphorinacitri and black aphids (Toxopteraaurantii and T. citricidus) are major pests of citrus. In NE region. Leaf miner, Phyllocnistiscitrella is also equally important and damages at nursery and plants during each new flush. Other pests of economic importance includes lemon butterfly, leaf mining beetles, tobacco caterpillars, leaf folder, looper, mealy bugs, scales, orange shoot borer, bark eating caterpillar, fruit sucking moths and fruit flies etc. (Azad Thakur et al., 2012).Because the inside of an orange is divided into segments, the initial internal injuries caused by the fly larvae were usually confined by the segments. Fly larvae were first detected by X-ray images of an orange into which eggs had been implanted for 2 days (as shown in Fig. 3(a)). The best X-ray tube voltage for X-ray photography of oranges was 75 kVp. Since the internal structures are more complicated than those of the fruits described above, and the segments provide a strong contrast on X-ray images, a topview X-ray image gave a clear indication of the location of the injury (Fig. 3(b)). The segmentation result is shown in Fig. 4(c), the proposed image processing algorithm accurately segmented the infested sites inside the orange. It is worth to mention that, in the X-ray image, the core of the orange was also segmented(Chuang et al., 2011)



(a) (b) (c)

Fig.3Experimental results of orange. (a) Photographs of an orange cut in different areas showing the internal injuries, (b) X-ray image scanned by the X-ray scanning system, and (c) segmentation results of the proposed image processing algorithm (Chuang et al., 2011).

The reason is that the density and composition of the core are different from that of the pulp. This problem can be overcome simply by applying a circular mask at the center of the orange in the X-ray image. Thus, the core of the orange can be neglected in the process of detecting pest infestation sites (Chuang et al., 2011).

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

Guava

Guava is a climacteric fruit, during 2003-2004, the area under guava in Pakistan was declined to 61608 hectares with an average yield of 549599 tons (Anonymous, 2003-2004). Out of many causes for decline in its yield, insect pests contribute to the maximum strength. There are many fruit insect pests in almost all guava fruit growing areas of the world and their economic importance can be summarized as; they attack commercially produced fruits, some species have become pests in regions far removed from their native range, in such cases quarantine restrictions have to be imposed to limit further spread of fruit pests (Anonymous, 2003-2004).

The best X-ray tube voltage for X-ray photography of the guava was 75 kVp. Fig. 21(a) and (d) shows two guavas which were infested by oriental fly larvae; they had eggs implanted for 6 days. The X-ray images clearly revealed internal injuries at 3 days after egg implantation into the guavas. There were many tunnels detected on the X-ray image (Fig. 21(b)), and the proposed image processing algorithm extracted the infested sites internal of the guava (Fig. 21(f)). The extracted pattern clearly shows the evidence in the parts where the internal injuries were located. Fig. 21(d–f) clearly shows that the proposed image processing method still successfully extracted the infested sites even if the regions are relatively smaller. The detailed segmentation results are depicted in Fig. parts where the internal injuries were located. Fig. 21(d–f) clearly show that the proposed image processing method still successfully extracted the infested sites even if the regions are relatively smaller(Chuang et al., 2011).

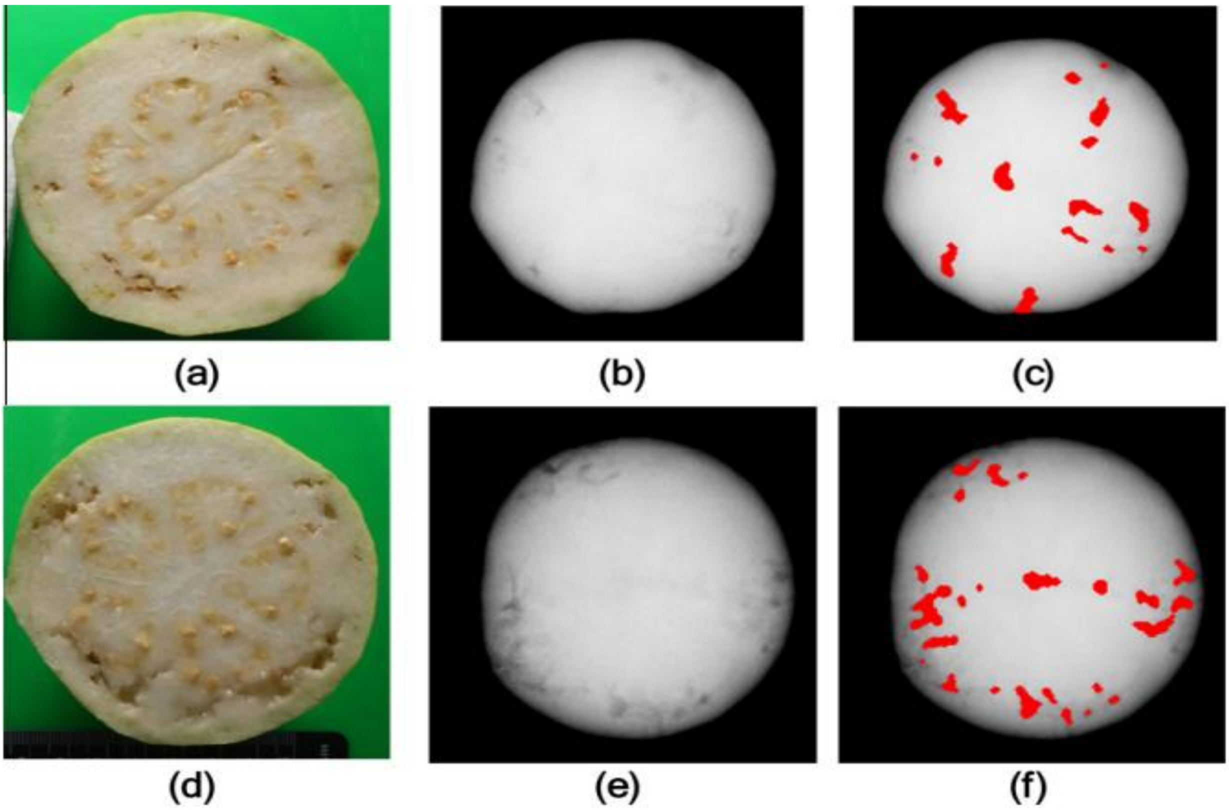


Fig.4 Photographs of two guavas taken after eggs were implanted into surface and cut in the center (a and d), X-ray images (b and e) successfully revealed signs of injury which were detectable as tunnels in the X-ray image, detection result is shown in (c and f)(Chuang et al., 2011)

Annals of R.S.C.B., ISSN:1583-6258, Vol. 26, Issue 1, 2022, Pages. 164 - 173
Received 08 November 2021; Accepted 15 December 2021.

Limitation

X-ray inspection has a number of distinct disadvantages including its relatively high cost and the need for high voltage power supplies to generate X-rays(R. P. Haff et al., 2008). X-ray inspection also has a number of perceived disadvantages, e.g. the perception that X-ray inspection irradiates food. However, the X-ray dose used for inspection purposes is significantly lower than that for irradiation and does not affect the safety, quality or nutritional value of foods(Organization, 1999).[5] Concern has been expressed that operators may be exposed to harmful levels of radiation from X-ray inspection systems. However, under normal circumstances the level of radiation that an operator in direct contact with an X-ray system will receive is less than that received in a year from natural backgroundradiation.

As the capability of X-ray inspection to detect contaminants is directly related to the density of the product and the contaminant, there are some contaminants which X-ray inspection systems have difficulty in detecting and imaging. These include hair, paper/cardboard, low density plastics and stone, string, wood and soft bone tissue such as cartilage(R. P. Haff et al., 2008)(Graves, Smith, Batchelor, & Technology, 1998).Other inspection technologies and controls are often used to identify these low density contaminants. However, advances in X-ray inspection technology and particularly coupling of other technologies to improve imaging are addressing some of this limitations(R. P. Haff et al., 2008)(Mery et al., 2011).

Conclusion

The present paper reviews and summarizes the x-rays technique that has been used for insect infestation detection in fruits and vegetables, and also discusses main merits and drawbacks of this technique for real-time monitoring in industrial applications. On the other hand, traditional sorting techniques, including manual sorting, are generally inadequate for the detection and removal of fruits with hidden internal damages have been reported. As an estimated that only about 35% infected fruits was detected by trained inspectors. Therehave many methods reported for insect detection but the x-rays detection methods most common and cheaper.

Contribution of Author

Conceptualization and Writing of the original draft S.K, revision and editing of the final version , K.U.R, H.A, M.I, M.I, M.J, R.D.K and Z.L, supervision, Z.X. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare that they have no conflicts of interest.

References

1. Chuang, C.-L., Ouyang, C.-S., Lin, T.-T., Yang, M.-M., Yang, E.-C., Huang, T.-W., . . . agriculture, e. i. (2011). Automatic X-ray quarantine scanner and pest infestation detector for agricultural products. *77*(1), 41-59.
2. Daane, K. M., & Johnson, M. W. J. A. r. o. e. (2010). Olive fruit fly: managing an ancient pest in modern times. *55*, 151-169.
3. Fenton, F., & Waite, W. W. J. J. A. R. (1932). Detecting pink bollworms in cottonseeds by the X-ray. *45*, 347-348.
4. Gould, G. W., Abee, T., Granum, P. E., & Jones, m. V. J. I. j. o. f. m. (1995). Physiology of food poisoning microorganisms and the major problems in food poisoning control. *28*(2), 121-128.

5. Graves, M., Smith, A., Batchelor, B. J. T. i. F. S., & Technology. (1998). Approaches to foreign body detection in foods. *9*(1), 21-27.
6. Haff, R., & Slaughter, D. J. T. o. t. A. (2004). Real-time X-ray inspection of wheat for infestation by the granary weevil, Sitophilus granarius (L.). *47*(2), 531.
7. Jackson, E., & Haff, R. (2006). *X-ray detection and sorting of olives damaged by fruit fly*. Paper presented at the 2006 ASAE Annual Meeting.
8. Karunakaran, C., Jayas, D., & White, N. (2002). *X-ray image analysis to detect infestation due to Cryptolestes ferrugineus in stored wheat.* Paper presented at the IEEE CCECE2002. Canadian Conference on Electrical and Computer Engineering. Conference Proceedings (Cat. No. 02CH37373).
9. Karunakaran, C., Jayas, D., & White, N. J. B. E. (2004). Identification of wheat kernels damaged by the red flour beetle using X-ray images. *87*(3), 267-274.
10. Keagy, P., & Schatzki, T. (1991). Effect of image resolution on insect detection in wheat radiographs.
11. Keagy, P. M., Parvin, B., & Schatzki, T. F. (1995). *Machine recognition of navel orange worm damage in x-ray images of pistachio nuts.* Paper presented at the Optics in Agriculture, Forestry, and Biological Processing.
12. Kendra, P. E., Montgomery, W. S., Niogret, J., Peña, J. E., Capinera, J. L., Brar, G., . . . Heath, R. R. J. J. o. c. e. (2011). Attraction of the redbay ambrosia beetle, Xyleborus glabratus, to avocado, lychee, and essential oil lures. *37*(9), 932-942.
13. Khan, S., Xiaobo, Z., Ilyas, M., Rahman, K., Khan, R., Shahid, K., . . . Irfan, M. J. A. o. t. R. S. f. C. B. (2021). Fraud Food and Food Spoilage Detection by Non-Destructive Technologies. *25*(7), 1389-1405.
14. Khan, S., Xiaobo, Z., Ilyas, M., Rahman, K. U., Khan, R. D., Irfan, M., . . . Mumtaz, T. Application of the lectin and non-lectin genes in transgenic crops.
15. Kim, S., & Schatzki, T. J. T. o. t. A. (2001). Detection of pinholes in almonds through x–ray imaging. *44*(4), 997.
16. Mery, D., Lillo, I., Loebel, H., Riffo, V., Soto, A., Cipriano, A., & Aguilera, J. M. J. J. o. F. E. (2011). Automated fish bone detection using X-ray imaging. *105*(3), 485-492.
17. Moscetti, R., Haff, R. P., Stella, E., Contini, M., Monarca, D., Cecchini, M., . . . Technology. (2015). Feasibility of NIR spectroscopy to detect olive fruit infested by Bactrocera oleae. *99*, 58-62.
18. Organization, W. H. (1999). *High-dose irradiation: wholesomeness of food irradiatied with doses above 10 kGy* (Vol. 890): World Health Organization.
19. Schatzki, T., Wilson, E., Kitto, G., Behrens, P., & Heller, I. J. J. o. E. E. (1993). Determination of hidden Sitophilus granarius (Coleoptera: Curculionidae) in wheat by myosin ELISA. *86*(5), 1584-1589.
20. Yang, E.-C., Yang, M.-M., Liao, L.-H., Wu, W.-Y., Chen, T.-W., Chen, T.-M., . . . Jiang, J.-A. J. F. E. (2006). Non-destructive quarantine technique-potential application of using X-ray images to detect early infestations caused by Oriental fruit fly (Bactrocera dorsalis)(Diptera: Tephritidae) in fruit. *26*, 171-186.
21. Zalom, F. G., Peng, C. Y., Toscano, N. C., & Hummel, N. A. (2003). *Reproductive biology and physiology of female Homalodisca coagulata.* Paper presented at the Symposium Proceedings.