Adoption of Thermal Treatment Technology (TTT) for Sustainable Post-Harvest Pest Control: A Case Study of Dried Fig Producers in Aydın, Turkey

Department of Agroecology and Plant Production, University of Agriculture in Krakow, Al. Mickiewicza 21, 31-120 Krakow, Poland; masoomeh.shemshad-shamsabad@student.urk.edu.pl

Post-harvest loss reduction is essential for sustainable food systems and food security (Kikulwe et al., 2018).

Pests destroy crops sufficient to feed over **1 billion people**, emphasizing the urgency of effective pest control (Birch et al., 2011).

•**Chemical pesticide era (post-Green Revolution):**
- •Increased yields, **but**
- •Caused environmental damage & contributed to climate change (Deguine et al., 2021; Shah et al., 2021).

•**Consequences of pesticide overuse:**
- •Resistance in pest species
- •Soil and water pollution
- •Toxic residues in food → food safety risks (Karuppuchamy & Venugopal, 2016; FAO, 2003)

•**International concern:**
Pesticide residues now central in **global health and trade debates** (Wilson & Tsunehiro, 2001).

•**Shift to Integrated Pest Management (IPM):**
Introduced in the 1970s as an **eco-friendly, knowledge-based approach**, combining:
- •Pest biology
- •Cultural & agronomic practices
- → Reduces chemical dependence, lowers costs, and supports safer food systems (Kogan, 1998; Bueno et al., 2021).

Thermal Treatment Technology (TTT) in IPM Framework

IS A PHYSICAL PEST CONTROL METHOD

- Effective in reducing post-harvest losses (FAO, 2013)
- Chemical-free & suitable for organic farming (Escribano & Mitcham, 2014)
- Challenges in IPM / TTT Adoption
  - Requires supportive policies & updated regulations
  - Needs institutional coordination
  - Must align with local socio-cultural contexts (Prokopy & Kogan, 2009)

Global Importance of the Dried Fig Industry

The dried fruit industry is known for its high added value and is a significant income source for many national economies.

Dried figs hold a prominent position globally due to their rich nutritional content:
- High in fiber, calcium, and iron
- Low in sugar

They are widely consumed as a healthy snack and functional food, especially by the elderly, diabetics, and athletes.

Fig Production Worldwide

Botanical name: *Ficus carica*, family Moraceae

Major producing countries: Turkey, Egypt, Morocco, Algeria, Iran

Turkey is the global leader in fig production:
- Produces 305.7 thousand tons out of 1.15 million tons worldwide
- Accounts for 51% of fresh and 53% of dried figs globally
- Exports 27.8 of 29.9 thousand tons of its dried fig production annually

Physical Pest Control in IPM

Focus: Modify environment to make it unsuitable for pests

Impacts pest:
- Feeding
- Reproduction
- Movement
- Survival

Key method: Thermal Treatment Technology (TTT)

Ideal for post-harvest and stored products (e.g., dried fruits)

Production Regions in Turkey

•Figs are cultivated in **60 out of 81 provinces**

•Main producing provinces (≈86% of national output):

Aydın, İzmir, Bursa, Mersin, Hatay

•Dried fig production is concentrated in the **Western Aegean region** (Aydın & İzmir)

•Dominant variety: **SARILOP (*Ficus carica L.*)**

•Approximately **90% of dried figs** from these regions are **exported**

POST-HARVEST CHALLENGES: PEST DAMAGE

Major storage pests affecting dried figs:

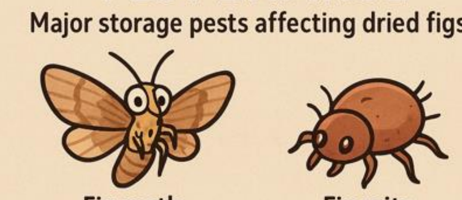


Fig moth (*Ephestia cautella*)

Fig mite

Impacts on product quality
- Decreased market value
- Contamination with waste residues
- Negative effects on appearance, safety, and export potential

Phase-Out of Methyl Bromide

•**Methyl bromide (CH_3Br)** was historically used to control storage pests in dried fruits, nuts, and cereals.

✓ Banned due to **ozone-depleting effects** under the **Montreal Protocol**:
- ✓ Developed countries phased out by **2005**
- ✓ Developing countries by **2015**

After the Ban: Ineffective Alternatives

•Turkey adopted **phosphine fumigation** and **ethyl formate**

✓ However, pests developed **resistance**, reducing effectiveness

✓ Result: Higher infestation risk in dried fruits

Health and Export Challenges

✓ First major contamination cases in Europe linked to **Carpoglyphus lactis L.**
- ✓ 13% of 180 imported samples contaminated
- ✓ Found in **apricots, figs, plums, raisins**
- ✓ Health risks: **allergen production, mycotoxin-carrying fungi**

•Aflatoxin issue:
- ✓ **32%** of 4,917 dried fig samples tested positive
- ✓ **9.8%** exceeded EU limits

Impact on Turkish Exports

Decline in exports to U.S., France, Germany, Italy, New Zealand, Canada (–2% in 2021)
- 12% drop in national dried fig production
- Projected further decline by 2025

Growing Demand for Safe & Organic Foods
- Increased global awareness of food safety
- Rising demand for organic, chemical-free products
- Turkey uses 33,000 tons of pesticides annually→ raises residue concerns in exports

Stricter EU Regulations
- EU imposed special import conditions (2002) for Turkish figs, hazelnuts, pistachios
- Aim: Protect consumer health & maintain food safety standards
- Pressure on Turkey to reform pest control practices

Need for Sustainable Pest Management
- Market shifting toward environmentally friendly production methods
- Current pest control system in Turkey faces a management crisis
- Sustainable reform is critical to maintain global leadership

Role of Sustainable Technologies

•Adoption of **Global GAP principles** (environmental, economic, social)

•Sustainable technologies must be:
- ✓ Environmentally friendly
- ✓ Economically viable
- ✓ High food safety standards

Thermal Treatment Technology (TTT)

•A strong alternative to chemical fumigation

•Benefits:
- ✓ Kills all pest stages
- ✓ No chemical residues
- ✓ Low environmental impact
- ✓ Fungicidal properties
- ✓ Easy application

Technology Adoption: A Social Challenge

•Adoption is not only technical—it's **behavioral and communal**

•Requires **participation of farmers and stakeholders**

•Success depends on **collective decision-making**, not individual effort

Research Focus

•**Central Question:**

How can the adoption of new pest management techniques be effectively facilitated?

•**Aim of Study:**

To identify key **behavioral and social factors** influencing the adoption of **Thermal Treatment Technology (TTT)** in dried fig production

What is AgroEcoTech?

AgroEcoTech integrates agroecological principles with modern technologies to enhance the sustainability of farming systems.

Aims to:
- ✓ Optimize resource use
- ✓ Increase productivity
- ✓ Reduce environmental impact

Includes technologies such as:
- ✓ Precision agriculture
- ✓ Renewable energy systems
- ✓ Eco-friendly pest control (e.g. thermal treatments)

AgroEcoTech & Global Challenges

Essential for sustainable agricultural intensification

Responds to major global issues:
- Food insecurity
- Climate change

AgroEcoTech & Global Challenges

Essential for sustainable agricultural intensification

Research confirms AgroEcoTech's role in achieving Sustainable Development Goals (SDGs)

Thermal Treatment Technology (TTT)

Safe alternative to chemical pesticides

Advantages:
- Kills all pest life stages
- No chemical residues
- Low environmental impact
- Fungicidal properties
- No resistance development
- Easy to apply

Organizations for IPM

Organizations like OECD promote IPM as:

Global Support for IPM

Organizations like OECD promote IPM as:
- Efficient
- Safe
- Cost-effective

Challenges for adoption:
- Need for infrastructure and investment
- Farmer awareness and training
- Long-term policy and community support

Aydın Province: Heart of Global Dried Fig Production

- ❑ **Location:** Southwestern Turkey, Aegean Region
- ❑ **Area:** 8,007 km² (3,092 sq mi)
- ❑ **Administrative Structure:** 17 districts
- ❑ **One of Turkey's most fertile agricultural regions**

Global Production Leader – Aydin Figs (Turkey)

SarilorTop (Izmir) Local Variety
- High-quality figs with unique flavor profile

•Cultivated in the Aegean region for **thousands of years**

❑ Recognized internationally:
- ❑ Granted **Protected Designation of Origin (PDO)** by the **European Commission** in 2016
- ❑ Registered as **"Aydın Inciri"**

Global Production Leader Turkey

Turkey = 60% of world dried fig production (~120,000 tons)

Aydin alone produces 55,000–60,000 tons, ≈ 85% of Turkey's output

Production spread over:
- 30,000 fig orchards
- 50,000 hectares of land
- ~10 million fig trees

Dominated by small-scale family farmers

Ideal Climate & Soil for Fig Cultivation

•**Climate:**
- •Mild, rainy winters
- •Hot summers (30°C – 40°C, July–September)

•**Relative Humidity:** 45% – 50%

•**Soil:** Alluvial & clay-loam

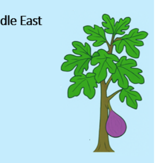
•**Average Annual Rainfall:** ~650 mm

•These natural conditions make Aydın **perfect for dried fig cultivation**

Fig characteristics

Fig (*Ficus carica L.*): Overview

- •Belongs to the Moraceae family
- •Native to **Western Asia and the Middle East**
- •Cultivated for:
  - •Edible fruit
  - •Ornamental purpose



Tree Characteristics

- •**Gynodioecious** (functionally dioecious) and **deciduous**
- •Height: up to **10 meters**
- •**Leaves:** Fragrant, deeply lobed (3–5 segments)
- •**Reproductive structure:** Syconium — hollow, fleshy inflorescence with multiple unisexual flowers

Growth Conditions

- •Thrives in **well-drained soils**
- •Prefers **dry, sunny climates** with deep, fresh soils
- •Can grow up to **1,700 m above sea level**
- •**Highly tolerant** to high temperatures and low water availability

Global and Turkish Production

- •Widely cultivated in **Mediterranean countries**
- •**Turkey:**
  - •Largest global producer and exporter of figs
  - •Most dried figs come from **Aydın Province** (Aegean region)

❑ **For designing the questionnaire behavioral models was studied. As TTT adoption in agriculture is a multifaceted process shaped by a combination of theoretical frameworks, behavioral dynamics, and socio-economic conditions.**

❑ **Utilizing well-established models—such as DOI, TAM, UTAUT, and the TPB—enables stakeholders to better understand the factors influencing farmers' decision-making.**

❑ **Effectively addressing adoption barriers through targeted policies, financial incentives, educational initiatives, and community involvement can significantly enhance the uptake of TTT, fostering a transition toward more sustainable agricultural practices and promoting its widespread integration within the farming sector.**

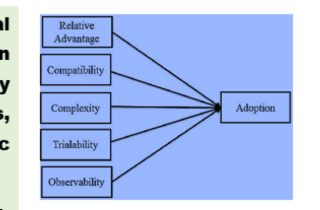


Fig 2. DOI Theory (Roger, 2003)

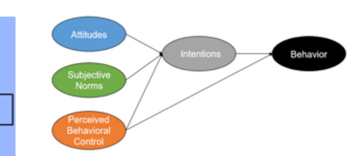


Fig 4. Technology Acceptance Model (Davis, 1989

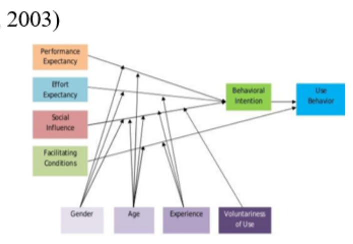
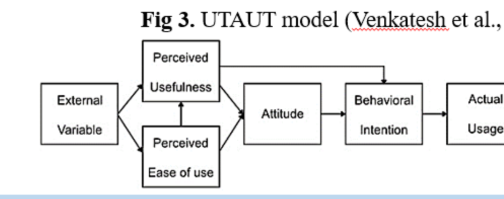


Fig 3. UTAUT model (Venkatesh et al., 2003)



In this study, a multinomial logistic regression model was used to analyze farmers' behaviors in adopting TTT. The goal of this analysis was to predict the impact of social, and economic factors on the adoption of agricultural TTT by farmers.

Table 1. Multinomial Logistic Regression Results (Predicting Adoption of TTT)

Variable	Coefficient (β)	Standard Error (SE)	z-value	p-value
Access to Training Services	0.85	0.25	3.40	0.0007
Financial support	1.12	0.31	3.61	0.0003
Farm Size	0.54	0.19	2.84	0.0045
Marketing support	0.73	0.22	3.32	0.0009
Farm Ownership	0.67	0.21	3.19	0.0014
Age	-0.36	0.14	-2.57	0.0102

The results of the multinomial logistic regression model indicate that both institutional support (training, finance, marketing) and structural characteristics (farm size, ownership, age) have a statistically significant effect on the likelihood of adopting Thermal Treatment Technology (TTT) among farmers.

Access to education resources ($\beta = 0.85$, $p = 0.0007$) has a strong positive and statistically significant effect on adoption. Farmers with better access to educational resources are more likely to adopt TTT, possibly due to increased awareness and understanding of the technology (Feder et al., 1985; Astaw & Admassie, 2004).

Financial support ($\beta = 1.12$, $p = 0.0003$) is also a key determinant. The high coefficient suggests that access to loan or subsidies greatly increases the probability of adopting TTT (Abdulai & Huffman, 2005; Kassie et al., 2011).

Based on the results regarding farm size ($\beta = 0.54$, $p = 0.0045$), larger farms are more likely to adopt the technology, This could be because larger operations have more resources and greater incentives to invest in innovative solutions (Doss & Morris, 2000; Pannell et al., 2006).

Farmers receiving marketing assistance are more likely to adopt TTT ($\beta = 0.73$, $p = 0.0009$), likely due to better access to markets or more confidence in selling treated products (Moser & Barrett, 2006; Teklewold et al., 2013).

Ownership of the form, as opposed to renting or sharecropping, positively influences adoption ($\beta = 0.67$, $p = 0.0014$), Owners may be more willing to invest in long-term improvements (Soule et al., 2000, Gebremedhin & Swinton, 2003).

Regarding **age** ($\beta = -0.36$, $p = 0.0102$), the negative coefficient indicates that older farmers are less likely to adopt TTT. This may be due to lower risk tolerance, resistance to change, or limited planning horizons compared to younger farmers (Adesina & Baidu-Forson, 1995; Tey & Brindal, 2012).

6.2. Model Significance & Fit Statistics

•**Purpose:** Assess the fit and explanatory power of the multinomial logistic regression model for **TTT adoption**

•**Key Results:**
- **-2 Log Likelihood:** 486.723 → indicates deviance from perfect fit
- **Chi-Square (18 df):** 118.564, **p = 0.000** → model significantly improves prediction over null model
- **Cox & Snell R^2:** 0.432 → explains 43.2% of variance
- **Nagelkerke R^2:** 0.587 → explains 58.7% of variance
- **McFadden R^2:** 0.294 → indicates good model fit (values >0.2 acceptable)

•**Sample:** 170 farmers → sufficient for reliable analysis

Conclusion:

•Model demonstrates **moderate to strong fit**

•Social and economic variables collectively **significantly explain TTT adoption behavior**

Table 2. Multinomial Logistic Regression Model Fitting Information and Case Processing Summary

Criteria	Value	Statistical Test	Value
-2 Log Likelihood	486.723	Chi-Square	118.564
Model (Final)	—	df	18
Significance (p-value)	—	Sig.	0.000
Cox and Snell R²	0.432	Nagelkerke R²	0.587
McFadden R²	0.294	Subpopulation (Valid)	170

Policy Implications

- Targeted interventions to enhance TTT adoption:
  - Capacity-building & training programs
  - Access to financial instruments (subsidies, loans)

Market Development Support

- Recognize farmer heterogeneity (age, landholding size, tenure) for inclusive programs
- Future research: include environmental and psychological variables to deepen understanding of adoption behavior