J. Agr. Sci. Tech. (2018) Vol. 20: 205-219

Ecological Consequences of Nanotechnology in Agriculture: Researchers' Perspective

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ABSTRACT

Despite the broad applications of nanotechnologies in the present age, there are concerns about its ecological consequences. In this regard, the purpose of this study was to analyze ecological consequences of nanotechnology in the field of agriculture. The research method was descriptive, which was carried out by a survey technique for gathering data. The statistical population of the study included all researchers, experts, and faculty members of national agricultural research institutes and centers across Iran (N=190); out of them, 123 individuals were selected by using Krejcie and Morgan sample size Table along with stratified random sampling method with proportional assignment (n=123). The research instrument was a questionnaire whose face and content validity was confirmed by a number of faculty members of agricultural extension and education and experts in the field of nanotechnology. The reliability of ecological consequences of nanotechnology items was also obtained by a pilot study using Cronbach's alpha coefficient (α= 0.78). To identify the ecological consequences of nanotechnology by taking advantage of factor analysis, five factors entitled "social consequences", "health-care consequences", "economic consequences", "cultural consequences", and "biological consequences" were extracted. As a whole, these factors explained 58.40 percent of the total variance of ecological consequences of nanotechnology in the field of agriculture.

Keywords: Ecological consequences, Cultural consequences, Economic consequences, Health-care consequences, Social consequences.

INTRODUCTION

Scientific developments and technological innovations in the twentieth century have led to significant achievements in agricultural production in many countries (Moradi *et al.,* 2011). Today, human societies lie in the culmination of the revolution of new technologies and this has brought extremely dramatic changes in the methods and approaches of agricultural activities (Shiri *et al.,* 2011). In fact, the convergence of the triple technologies, including Information and Communication Technologies (ICTs), Biotechnology, and Nanotechnology have been the axial focus of the contemporary technological advances. Undoubtedly, these three technologies have a profound impact on the future of agriculture and the environment. In the meantime, many experts and scholars believe that various fields and majors will have no chance for growth and expansion without recourse to nanotechnology in the coming decades (Rezaei *et al.,* 2012).

Nanotechnology, as a new leading technology, has proved its importance in agricultural sciences and its related industries towards the resolution of the problems and shortcomings in many arenas of science and technology. The term Nano has been derived from the Greek root of *Dwarf*, which means short height or gnome and refers to the dimensions whose largeness equals a

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billionth (10^{-9}) of each quantity (Warad and Dutta, 2006).

The first spark of nanotechnology (still not known by this name at that time) was created in 1959. In this year, Richard Feyman proposed the idea of nanotechnology via a speech entitled "There's Plenty of Room at the Bottom". He theorized that it would be possible to manipulate the molecules and atoms directly in the near future. The term nanotechnology was first introduced by Pratima Nikaljeo Taniguchi, the Professor of Tokyo Science University in 1974. He used this term to describe the precise machining of materials (tools) within atomic-scale dimensional tolerances. In 1986, this word was recreated and redefined by Eric Derecxler in a book entitled "Engines of Creation: The Coming Era of Nanotechnology". He explored this word more deeply in his doctoral dissertation and developed it later on in a book entitled "Nanosystems: Molecular Machinery, Manufacturing, and Computation" (Poursaeed *et al.,* 2012). In this regard, there are three following features at play for the definition of nanotechnology from the perspective of National Nanotechnology Initiative.

- Research and technology development at atomic, molecular or macromolecular levels on a scale of one to 100 nanometers in size,
- The creation and use of the structures, devices and systems, that have novel properties and functions because of their small or middle size, and
- Ability to control or manipulate the atomic level (Maghabl *et al.,* 201l; Naghdi *et al.,* 2015)

The ecology includes humans and the environment as well as human relationship with their environment (Bijani and Hayati, 2015). In this regard, nanotechnology pioneers believed that this technology enjoys the necessary ability in reducing ecological problems, particularly environmental issues through identification and optimal control of the pollutants arising from a wide range of sources of pollution.

However, there has been always this concern regarding the emergency of a technology. In fact, when a technology comes into existence, despite tackling some problems, it will also bring new problems whose resolution requires more expensive and complex specialties (Nad, 2005).

Despite the rapid development and growth of nanotechnology usages and applications, very little research has been done on nanoparticle risk assessment and measurement in eco-systems. Direct and indirect effects of nanotechnology on the environment can be evaluated from different aspects; and various concerns resulting from physical and chemical properties of nanoparticles are currently emerging (Xiaojia and Huey-Min, 2016).

People have different orientations and positions regarding the use of technology. In terms of the effects of new technologies, many theoretical approaches have claimed that the changes resulting from the entrance of technology are positive in the future achievements and, accordingly, technology is a factor of development and change (Shahhosseini, 2015). One of the key issues facing the third world countries is how to control the consequences of the transfer of large industries and sophisticated technologies until they will enter the optimal path. In many cases, the advent of industry and technology has led to desirable economic outcomes; however, it has had some adverse environmental and social impacts on the community. In the meantime, severe environmental changes resulting from industries and technologies have often caused irreparable damages (Tavakol and Nozari, 2013; Najafi Alamdarlo, 2018).

Dunmade (2002) classified the effects and consequences of technology and industry into four technical, economic, socio-political, and environmental dimensions. In other words, he believed that one needs to take into consideration the consequences of the four above-mentioned domains in the assessment of major industries and advanced technologies. Dunmade (2002) considered some indicators for the measurement of each dimension. Assessing the consequences of industry, he selected indicators such as material infrastructures and technical knowledge from the technical dimension and chose such indicators as the consumption rate of reserves, the release of polluting substances in the environment, and conservation of the resources from the environmental dimension (Valizadeh *et al.*, 2018). In addition, he considered such indicators as employment, income, usability, and necessary local maintenance from the economic dimension; and opted for such indicators as the socio-cultural influences, level of awareness, and acceptability to assess the socio-political dimension (Dunmade, 2002). Accordingly, it seems that the economic, social, and environmental effects of the consequences of industry and technology should be given attention at the same time when studying them. Some experts believe that the notion of conflict of economic, social, and environmental interests is an axiom in the process of development; and this is true that economic development is associated with negative environmental and social consequences. The results of different studies and theories suggest that technological innovation is directly related to sustainable development. However, to achieve a suitable model of technological innovation, one needs to pay attention to factors, such as the correct analysis of environmental factors, the application of knowledge management, attitudes of human resources, the environmental effects of using technological innovation, and employment of appropriate indicators. In this way, the relevant ecological consequences of the effects of technology should receive the attention of professionals and experts of various industries in all aspects (Rezvani *et al.*, 2010; Mosavi & Esmaeili, 2012).

Nanotechnology is an emerging phenomenon that may bring risks to human ecology like any other technology in addition to its increasing contribution to the economy and life. The very small size and level of nanoparticles and nano-materials leads to the easy mobilization and new features of them that impose possible detrimental effects on human health, other creatures, and the environment. In 2003, Richard Errett Smalley, a Nobel Prize winner and one of the founders of nanotechnology, announced his concern over the issue of safety in technology. He stated that although nanotechnology encompasses all activities from medicine to environmental, engineering, biological, and legal domains, risk assessment and management should be carried out on nanotechnology like any other new technology (Council for Science and Technology, 2007).

Despite the rapid development and growth of nanotechnology applications, few studies have been done on nanoparticle risk assessment and measurement in eco-systems. At present, researchers and members of the community have expressed their concerns about the environmental impacts and toxicity of nanoproducts. In this regard, studies on the toxicity of nanoparticles are on the rise and many researchers believe that the toxicity of nanoparticles should be considered prior to their implementation on a large scale. Not much information is available about the effect of nanoparticles on human health and the environment as well as their negative effects and consequences on water, soil, and plants. Hence, it is likely that the presence of nanoparticles in these resources will be a serious threat to the creatures living in the resources (Shatkin, 2012). With the massive production of nano-based products, it is essentially required to investigate their potential toxic effects on human body and the environment and to evaluate this emerging technology (Soleimani *et al.*, 2015).

Due to the rapid growth of nanotechnology, its numerous applications, and the possibility of the occurrence of a wide range of human exposures; it is required to develop a scientifically validated and integrated framework that can assess the risks and consequences arising from the growth of this technology in suitable dimensions (Ebrahimi and Chokhanizade-Moghadam, 2014). Direct and indirect impacts of nanotechnology on the environment are among the different aspects that are worthy of consideration and investigation. The above-mentioned positive and negative effects should be carefully analyzed and identified and, thereby, pertinent solutions and remedies should be predicted to prevent the destructive consequences. This will be feasible only through doing broad and comprehensive research (Sabzali Parikhan *et al.,* 2016).

The assessment of new technologies should attempt to analyze and evaluate their wanted and unwanted achievements, opportunities, and risks. Technology assessment has been founded on this slogan that a new technology should be better than the previous technologies; otherwise, there is no need for such a technology. Better technology does not refer only to its scientific aspects, but it also refers to social, economic, and environmental dimensions. At the outset of the development of technology assessment, the research agenda focused on the social and economic negative capacities or unintended consequences of the development of new technologies. In this regard, the main function and objective was to issue the early warning about the effects of selecting a technology. For example, the use of stem cell technologies can bring about negative and unintended effects and consequences, such as genetic alterations, environmental pollutants, and so on in the long run, in addition to many positive effects. In recent years, technology assessment has become a participatory approach. It is notable that participatory approaches believe that networking and stakeholder engagement should be taken into account in the acceptance of a new technology in order to maximally reduce the negative and/or unwanted effects since any new technology can occasion some negative and unwanted effects. Thus, the influences of a technology should be assigned consideration in technology assessment; in other words, the identification, analysis, and estimation of its effects should be evaluated (Norozi, 2014).

With the emergence of the harmful effects of human activities towards the establishment of a trade-off and harmony between activities and ecologies, different methods and instruments have been developed and used (Salehi *et al.,* 2017). Environmental Impact Assessment (EIA) is among the very efficient methods that assess the effects of different sections or activities of a project on components of the environment through the analysis of the environment and understanding its importance. This method eventually proposes some strategies to create a greater consistency considering the obtained results. In general, the economic, social, and environmental developments constitute the main components of development. Although the purpose of such development is to improve the socio-economic status of a community, it is possible that various problems and issues, especially in terms of environmental and health aspects, arise in case of the non-comprehensiveness of the programs. Based on the proposed definition, the assessment of environmental consequences is the flow of a formal study that is used to predict the environmental consequences of a proposed project. In fact, studies on the assessment of environmental consequences act as a management tool for planners and decision-makers and as a supplement to other engineering and economic studies (Hayeripor, 2014). The eco-system factors that are identified and examined in this case specify the current situation of the environment and include such components as physical, socio-economic, cultural, and biological (flora and fauna) environments as well as the existing environmental pollution (air, soil, water, sound) (Monavari, 2009). Thus, the purpose of this study was to analyze ecological consequences of nanotechnology in the field of agriculture.

Theoretical Background

Various studies have examined different effects and consequences of nanotechnology. Some studies suggest that nanotechnology can have numerous effects and consequences, including health and environmental consequences, which can be positive or negative (Soleimani *et al.*, 2015; Shoja Alsadati and Hamedi, 2014; Cheraghi *et al.*, 2004). Others believe that nanotechnology can have significant positive effects on the economic growth of countries (Naghdi *et al*., 2015). Some studies have pointed to the conservation and sustainability of the culture of nanotechnology use. They believe that the use of nanotechnology can have positive environmental and health implications; furthermore, the culture of environmental protection can be promoted through the increase and production of green and clean materials (Pratima Nikalje, 2015). In a research entitled "The possible effects of nanoparticles on the environment and human", the results showed that the nanoparticles that are released into the atmosphere by diesel engine would have harmful and adverse effects on human health, the environment, and society. It is noteworthy that the research had been conducted through the review and integration of the studies and experiments done by other researchers. For the risk assessment of these nanoparticles on human health, the whole life cycle of these particles should be studied. This cycle includes the construction, maintenance and storage, distribution, application, and disposal method of the nanoparticles. The studies and experiments conducted in the field of nanotechnology show that engineered nanoparticles have potential positive and negative effects and consequences, which may impact the health, environmental, and social dimensions of societies (Mirbakhsh *et al.*, 2012). The arrival of any new material to the workplace and life may be associated with numerous potential and actual risks and losses. The results show that, in addition to the numerous benefits that it can bring in many aspects, nanotechnology may cause irreparable damage to water, soil, air, humans, and generally the environment in case of the absence of safety (Mazaheri Asadi and Gholami Qavamabad, 2010).

Maynard (2007) maintains that nanotechnology can have a large number of environmental, economic, social, cultural, and moral impacts and, thereby, it is necessary to conduct research and investigation in this area. Bond (2003) argues that nanotechnology can reduce production costs, improve energy economy, alter the labor market, change wages, create materials and products with a long life, change the treatment method of cancer, and produce new medical drugs for diseases. Therefore, nanotechnology has different social, economic, health, and environmental effects and consequences. The results of a study undertaken in the field of science and nanotechnology policy-planning by UK Council for Science and Technology indicated that nanotechnology brings environmental, health, and safety effects and consequences as well as social and ethical dimensions. Therefore, it is required to propose different mechanisms, including the creation of a management structure, the planning of extensive discussions and debates among people and experts, and networking among people so that these consequences can be soundly managed (Council for Science and Technology, 2007). Table 1 summarizes the literature review about the ecological effects of nanotechnology in this study.

Reflection on what was mentioned regarding the investigation of the possible consequences of nanotechnology and the variables used in the previous studies as well as the analysis of different experts' opinions leads one to social, economic, health, and cultural aspects as the factors that are influenced by nanotechnology. These consequences can be positive or negative. Accordingly, the following theoretical framework (Figure 1) has been presented.

MATERIALS AND METHODS

The present study was an applied research in terms of goal, quantitative regarding its nature, descriptive in terms of data analysis,

Table 1. A summary of the titles of previous studies on various consequences of nanotechnology.

Investigated variables	Research title	Reference
Environmental consequences	Nanoparticles impact on human and environment: A review of toxicity, exposure, control strategies, and future prospects	Soleimani *et al.* (2015)
Economic consequences	Effects of nano-technology on economic growth in selected countries	Naghdi *et al.* (2015)
Environmental, social, and health effects	The possible effects of nanoparticles on human health and the environment	Mirbakhsh *et al.* (2012)
Environmental effects (air, soil, water), social and health effects	Risk Assessment of Engineered Nanoparticles (ENPs)	Shoja Alsadati and Hamedi (2014)
The effects of nanotechnology on health, the effects of nanotechnology on the environment	Examining the impact of nanotechnology on medical and environmental sciences from the nanometric tools perspective	Cheraghi *et al.* (2004)
Health effects, environmental effects (water, soil, flora, fauna)	Health and Environmental Hazards of Nanotechnology	Mazaheri Asadi and Gholami Qavamabad (2010)
Health, economic, social, and environmental consequences of nanotechnology	Nanotechnology and its applications in medicine	Pratima Nikalje (2015)
Economic, social, health, and hygienic consequences	Former undersecretary of commerce for technology	Bond (2003)
Environmental, economic, social, and cultural consequences, development of ethical methods, training and awareness-raising programs and measures	Nanotechnology: the next big thing, or much ado about nothing?	Maynard (2007)
Environmental, health, and safety consequences of nano-materials; social and ethical dimensions of nanotechnology	Nano-sciences and Nanotechnology: A Review of Governments Progress on its Policy Commitments	The Council for Science and Technology (2007)

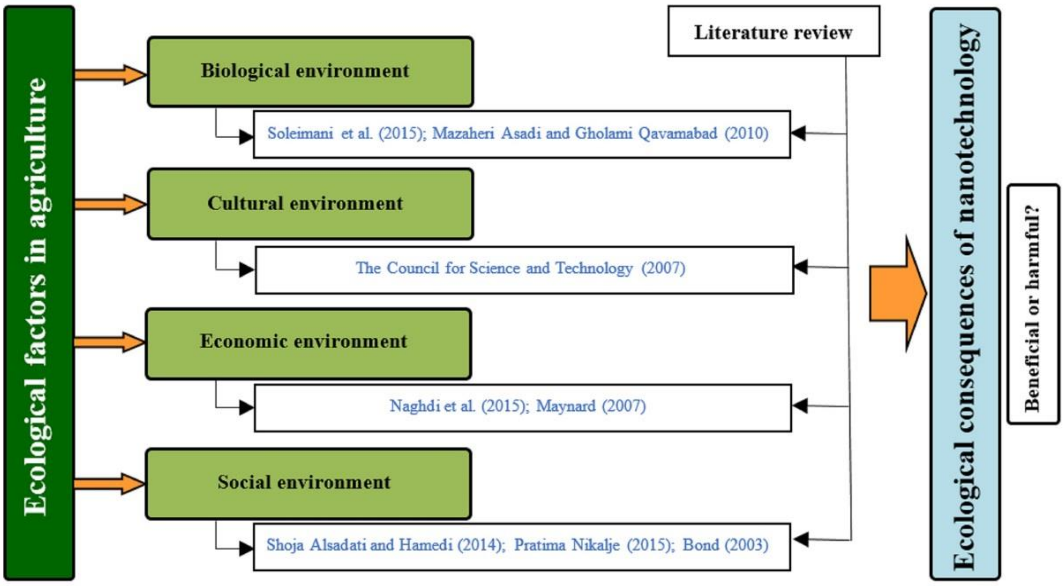

Figure 1. Theoretical framework: Assessment of ecological effects of nanotechnology on agriculture.

and survey in terms of data collection. The statistical population of this research included 190 faculty members and researchers active in nanotechnology domain at national agricultural research institutes and centers. These researchers were engaged in nano-based activities or were involved in a research project in this area. According to Krejcei and Morgan's Sample Size Table (Krejcei and Morgan, 1970), 123 participants were selected from the population through stratified random sampling method (Table 2). The data collection instrument included a questionnaire consisting of two sections, i.e. environmental consequences of nanotechnology in the field of agriculture and demographic and professional information of the nanotechnology researchers. In terms of the face and content validity of the questionnaire, it was handed to a panel of experts in agricultural extension and education and a number of experts active in nanotechnology in agriculture. To determine the reliability of the questionnaire, 30 copies of the questionnaire provided by researchers and faculty members at Faculty of New Sciences and Technologies (FNST), University of Tehran. After data collection, Cronbach's alpha was calculated for the items pertaining to the measurement of ecological consequences of nanotechnology in agriculture (including 28 items, Table 3), which was equal to 0.78 ($\alpha = 0.78$). The data were analyzed in $SPSS_{22}$.

RESULTS AND DISCUSSION

The results of this study showed that 63.3% of the total of 118 researchers participating in this study were male and 22% of them were female. In addition, the mean value of 45 years was obtained for participants' age. In terms of education, the highest frequency pertained to doctoral degree, which constituted 58.5% of the statistical population and the rest of the participants (34.7%) held master's degree (No response = 6.8%). The mean value of 12.40 years was obtained for the participants' research background. The data relating to researchers' characteristics showed that about 65.3% of the subjects participated in educational programs related to nanotechnology, whereas 34.7% of them did not participate in educational programs. Moreover, the results suggested that 56.8% of the researchers had authored a work or more on nanotechnology.

Researchers' Views on Consequences of Nanotechnology

The obtained results of this research in relation to the consequences of nanotechnology in the field of agriculture and the environment are shown in Table 3.

Based on these research findings, the items of ‘enhancement of environmental protection culture using clean produced materials through nanotechnology’, ‘nanotechnology leads to the increased quality of the manufactured health products’, ‘making water and soil pollutants safe and recyclability of the materials’, ‘development of other jobs and technologies associated with the profession of agriculture’, and ‘Economical desalination of salt water’ are placed in the top ranks. In addition, research findings revealed that the main consequences of nanotechnology happen in agriculture and the environment. However, the respondents assigned less importance to the following issues: ‘creation of new jobs and job diversity in agricultural profession’, ‘nanoparticles reduce the growth of plant roots, such as corn, cucumbers, carrots, etc.’, ‘nanoparticles cause lung injury’, ‘the entrance of nanoparticles into water has some detrimental effects on certain kinds of fish’, and ‘nanoparticles cause skin inflammation and lesions’.

Factor analysis was used to classify the items in Table 3 into a limited number of factors so that a better understanding of the ecological consequences of nanotechnology

Table 2. Statistical distribution of the researchers active in the field of nanotechnology at research institutes and centers and extracted sample.

No.	Research center or institute	N [a]	Active people in nanotechnology [b]	n [c]	No	Research center or institute	N	Active people in nanotechnology (n)	n
1	Sugar Beet Seed Institute	89	7	5	12	Soil Conservation and Watershed Management Research Institute	51	8	5
2	Plant Improvement Research Institute	91	15	10	13	Silk Research Center	10	6	4
3	Research Institute of Horticulture	253	10	7	14	Haraz Extension and Technology Development Center	24	9	5
4	Rice Research Institute	37	6	4	15	National Salinity Research Center	7	3	2
5	Cotton Research Institute	26	6	4	16	Seed and Plant Certification and Registration Institute	22	8	5
6	Research Institute of Forests and Rangelands	144	6	5	17	Research Institute of Animal Science	36	9	7
7	Soil and Water Research Institute	43	8	5	18	Fisheries Research Institute	115	11	7
8	Research Institute of Agricultural Engineering	37	10	7	19	Vaccine and Serum Research Institute	118	15	10
9	Maragheh Dry Land Agricultural Research Institute	22	5	4	20	Imam Khomeini Higher Education Center	54	5	4
10	Plant Protection Research Institute	119	13	9	21	Scientific Applied Training Center	135	13	9
11	Agricultural Biotechnology Research Institute	30	12	10	22	International Institute for Caspian Sea Sturgeon	25	6	4

[a] Total No. of researchers (N): 1,488 people. [b] Total active people in nanotechnology: 191 people. [c] Sample (n): 123 people.

Table 3. Ranking of the items pertaining to the ecological consequences of nanotechnology.

Ecological consequences	Mean[a]	SD	Rank
Enhancement of environmental protection culture using clean produced materials through nanotechnology	4.04	1.11	1
Increased quality of the manufactured health products	3.76	1.04	2
Making water and soil pollutants safe and recyclability of the materials	3.75	1.01	3
Development of other jobs and technologies associated with the profession of agriculture	3.69	1.16	4
Economical desalination of salt water	3.66	0.79	5
Food security	3.60	1.02	6
Increased distance of social classes	3.56	1.09	7
Enhanced quality of agricultural products.	3.54	1.03	8
Increasing marketability of different products and plants by the production of seeds via nanotechnology	3.53	1.06	9
Molecular treatment of diseases, rapid diagnosis of diseases, and enhancement of the ability of plants to absorb the necessary materials	3.52	1.03	10
Creation of positive changes in people's consumption pattern	3.49	0.99	11
Increased resistance of the hull coatings of agricultural equipment and machinery	3.47	1.02	12
Changes in people's demands and expectations regarding services and products	3.47	1.13	13
Better packaging of agricultural products and foodstuffs	3.46	1.03	14
Purification and reduction of environmental pollution by nanotechnology catalytic converters	3.45	0.93	15
Enhanced quality of life.	3.39	0.93	16
Nanoparticles may increase the speed of bacterial mutations	3.38	1.04	17
Establishment of new factories and companies	3.38	1.06	18
Increased income through the production and export of agricultural products	3.37	1.07	19
Jeopardizing the privacy of individuals	3.36	1.04	20
Control and quick reporting and collection of environmental pollutants	3.33	1.03	21
Increased sports activities and improved leisure time through building stronger and cheaper recreational equipment and tools	3.32	1.10	22
Injustice in the distribution of wealth through the monopoly of this technology by certain people in power	3.25	1.08	23
Creation of new jobs and job diversity in agricultural profession	3.23	1.02	24
Reduced growth of plant roots, such as corn, cucumbers, carrots, etc.	3.15	1.09	25
Nanoparticles cause lung injury.	3.13	1.01	26
Entrance of nanoparticles into water has some detrimental effects on certain kinds of fish.	2.92	1.13	27
Nanoparticles cause skin inflammation and lesions.	2.91	1.19	28

[a] Mean ranges from 1 to 5. Five-point Likert scale (Strongly disagree = 1; Disagree = 2; Neutral = 3; Agree = 4, and Strongly agree = 5).

Table 4. Factor analysis of ecological consequences of nanotechnology in agriculture.

Factor	KMO	Bartlett's test	Sig.	Eigenvalue	Percentage of variance	Cumulative variance[a]
1				7.50	27.77	27.77
2				2.32	10.29	38.06
3	0.78	1243.78	0.000	1.90	7.80	45.86
4				1.59	6.69	42.55
5				1.36	5.85	58.40

[a] One of the criteria to determine factors is measuring the cumulative percentage variance. In social studies, analysts usually extracted continue operating as much as 60 percent of the total variance of variables In some cases lower than 60 percent, especially when the main criteria for factor determination is eigenvalue (should be more than 1), we can have a cumulative percentage variance lower than 60 percent (Mansourfar, 2006; Abbasian *et al.*, 2017; Majidi *et al.*, 2017).

in agriculture could be gained. KMO (Kaiser-Meyer-Olkin) measure of 0.78 and Bartlett's test value of 1,243.78 were obtained, which were significant at the level of 0.01 (Table 4). In addition, varimax rotation method was used to determine the simple structure of the component "ecological consequences of nanotechnology". According to the results of Table 5, the five extracted factors totally accounted for 58.40% of the total variance, which represented an acceptable percentage of the variance explained by the factors.

The status of the variables related to the

Table 5. Details of factors extracted from factor analysis.

Factors No	Factors Title	Items	Rotated factor matrix (After varimax rotation): Factor and factor loading 1	2	3	4	5
1	Social consequences	Nanotechnology enhances the quality of life.	**0.50** [a]	-0.21	-0.46	0.30	-0.08
		Food security for the community	**0.67**	0.18	-0.38	-0.03	-0.22
		Nanotechnology enhances the quality of agricultural products as perceived by the society.	**0.66**	0.08	-0.34	0.09	0.09
		Increased distance of social classes	**0.59**	0.12	-0.27	-0.18	0.22
		Development of other jobs and technologies associated with the profession of agriculture	**0.58**	0.26	-0.32	0.13	0.27
		Injustice in the distribution of wealth through the monopoly of this technology by certain people in power	**0.63**	0.29	0.01	0.43	0.07
		Changes in people's demands and expectations regarding services and products	**0.50**	-0.21	0.46	0.30	-0.08
2	Health-care consequences	Nanotechnology leads to the increased quality of the manufactured health products	0.157	**0.56**	-0.20	0.36	0.02
		Nanoparticles may increase the speed of bacterial mutations	0.224	**0.46**	0.34	0.29	-0.24
		Nanoparticles cause lung injury.	0.32	**0.44**	0.29	0.13	0.21
		Nanoparticles cause skin inflammation and lesions.	0.31	**0.42**	0.33	-0.42	0.08
3	Economic consequences	Better packaging of agricultural products and foodstuffs	0.17	-0.01	**0.54**	0.19	0.28
		Increasing marketability of different products and plants by the production of seeds via nanotechnology	0.22	-0.09	**0.56**	0.33	-0.18
		Establishment of new factories and companies	0.21	0.14	**0.45**	0.41	0.36
		Creation of new jobs and job diversity in agricultural profession	0.29	0.08	**0.33**	0.02	0.13
		Nanotechnology increases income through the production and export of agricultural products	-0.28	0.04	**0.54**	-0.96	0.31
4	Cultural consequences	Creation of positive changes in people's consumption pattern	-0.23	-0.10	-0.35	**0.62**	-0.29
		Enhancement of environmental protection culture using clean produced materials through nanotechnology	-0.28	0.03	-0.25	**0.60**	0.23
		Jeopardizing the privacy of individuals	-0.38	0.22	0.01	**0.54**	0.28
		Increased sports activities and improved leisure time through building stronger and cheaper recreational equipment and tools	-0.05	0.17	-0.05	**0.56**	-0.04
5	Biological consequences	Economic desalination of salt water	-0.12	-0.01	-0.31	-0.19	**0.52**
		Purification and reduction of environmental pollution by nanotechnology catalytic converters	0.15	0.32	0.14	0.05	**0.45**
		Making water and soil pollutants safe and recyclability of the materials	-0.23	0.09	0.22	-0.12	**0.43**
		Molecular treatment of diseases, rapid diagnosis of diseases, and enhancement of the ability of plants to absorb the necessary materials	-0.34	0.19	0.12	0.17	**0.46**
		Increased resistance of the hull coatings of agricultural equipment and machinery	-0.16	0.34	0.14	0.32	**0.48**
		Control and quick reporting and collection of environmental pollutants	-0.27	0.07	-0.05	0.32	**0.57**
		Nanoparticles reduce the growth of plant roots, such as corn, cucumbers, carrots, etc.	-0.29	0.05	0.14	0.27	**0.45**
		The entrance of nanoparticles into water has some detrimental effects on certain kinds of fish.	-0.04	0.17	-0.05	-0.04	**0.56**

[a] Bold items indicate that the item has been loaded and it takes place on this factor.

environmental consequences of nanotechnology in the agricultural sector of Iran is presented in Table 5 according to the extracted factors (with the loading factors above 0.1) after varimax rotation. On the whole, the factor analysis led to the extraction of five factors, namely, "social consequences", "health consequences", "economic consequences", "cultural consequences", and "biological consequences", which constitute the ecological consequences of nanotechnology in agriculture (Figure 2).

CONCLUSIONS

This study was conducted with the aim of evaluating the ecological consequences of nanotechnology in agriculture from the perspective of the researchers in the National Agricultural Research Institutes and Centers of Iran. The results of the study showed that ecological consequences of nanotechnology in agriculture consist of five main underlying factors. According to Table 5, it is observed that the first seven items pertain to social issues and the improvement of quality of life. Therefore, the first factor can be named "social consequences of nanotechnology", which entails the consequences with social aspects. This finding is consistent with results of the studies done by Mazaheri Asadi and Gholami Qavamabad (2010); Mirbakhsh *et al.* (2012); Shoja Alsadati and Hamedi (2014); Maynard (2007); and Bond (2003).

The second factor is related to the

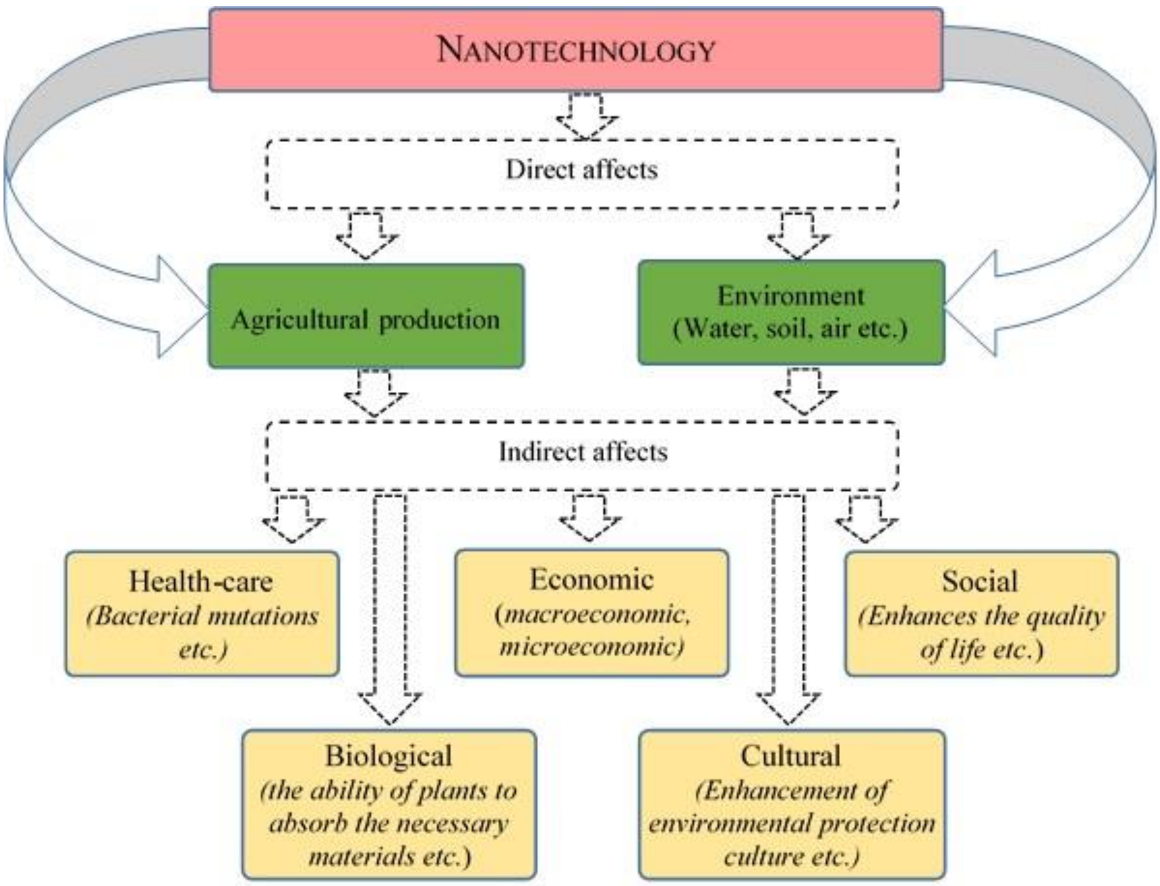

Figure 2. Extracted factors from items of ecological consequences of nanotechnology.

consequences that affect the health of individuals; hence, this factor can be named "health-based and hygienic consequences of nanotechnology". This finding is consistent with the results of the studies conducted by Mazaheri Asadi and Gholami Qavamabad (2010); Cheraghi *et al.* (2004); Mirbakhsh *et al.* (2012); Pratima Nikalje (2015); Soleimani *et al.* (2015); Council for Science and Technology (2007); and Bond (2003).

The third factor represents the effects and consequences that influence the economy. Therefore, this factor was named "economic consequences of nanotechnology". This finding is consistent with results of the studies carried out by Naghdi *et al.* (2015) Maynard (2007); and Bond (2003).

The fourth factor is associated with cultural influences in society. This factor was called "cultural consequences of nanotechnology". This result is consistent with those of the studies undertaken by Pratima Nikalje (2015); and Maynard (2007).

The fifth factor explains the consequences that nanotechnology may have on water, soil, flora and fauna. Thus, this factor can be named "biological consequences of nanotechnology". This is consistent with the research findings obtained by Soleimani *et al.* (2015); Mirbakhsh *et al.* (2012); Shoja Alsadati and Hamedi (2014); Cheraghi *et al.* (2004); Pratima Nikalje (2015); Mazaheri Asadi and Gholami Qavamabad (2010); Hodghe (2005); Council for Science and Technology (2007); and Bond (2003).

Accordingly, one may reach the conclusion that nanotechnology has widespread economic, social, cultural, biological, and health consequences in the eco-system, particularly in agriculture and the environment, which may lead to global challenges. These consequences can be positive or negative, depending on the researchers' attitudes and behaviors that assign positive or negative direction to the consequences. Therefore, the improvement of human behavior can be effective in the promotion and orientation of these consequences towards positive and desired outcomes. These behaviors can be positive, discreet, and responsible or negative and against the environment.

Based on the ranking of the items relating to consequences of nanotechnology and the review of the researchers' comments and opinions, it can be found that benefits have been generally cited by the researchers participating in this study prior to the perception of risks. Risk perception is essentially considered as mentioned benefits rather than as a major appraisal dimension. It is possible to greatly reduce the risk of such problems using preventive measures and solutions. Therefore, it is suggested that the risks and adverse effects of nanotechnology be minimized as much as possible through the improvement of the equipment, safety, and quality in the workplace; and the increase of the knowledge of researchers on how to treat nanotechnology effectively. In this regard, the future of nanotechnology is inevitably linked to interdisciplinary education and learning (Taqipour, 2016). The existence of this type of interdisciplinary education is absolutely necessary to tackle the important challenges that are created in the safety of nanotechnology as an emerging new field. In addition, safety budget must be considered as an integral part of the production and design of new products in order to contribute to the sustainable development of nanotechnology. In this context, the attraction of investment by the private sector can be of great assistance.

The promotion of mutual cooperation among universities, government, and the industry regarding the development of nano-safety and research on it is necessary to create, design, develop, and acquire value for nanotechnology advances along with public acceptance. This cooperation is not only necessary to generate knowledge, but it is also essential to provide investment options with knowledge-based production.

The public are more prone to react to the unproven dangers and consequences and some of their opinions are founded upon the baseless reports that they receive from the news media and non-governmental organizations. As long as there is a data chasm in nano-safety, the threats of known risks will be available despite the absence of necessary and sufficient evidence. This issue potentially prevents the development of market and technology. A key issue in this context is to effectively communicate, inform, and engage the public in useful discussions about the consequences of nanotechnology and clarification in this field.

The favorable promotion of nanotechnology can have an important role in building confidence and trust in this technology if it is accompanied by providing a credible pyramid of information, holding training courses, proposing risk prevention strategies, and providing necessary training and teaching regarding the identification of the safe and secure products with standard and secure tags of nanotechnology.

It is noteworthy that nanotechnology activities are being increasingly developed and spread in most areas, including agriculture, soil, water, horticulture, plant protection, food industry, and other areas. Therefore, emphasis should be placed on the empowerment of the necessary human resources as the infrastructure to provide scientific services and to hold training courses. In this way, it is possible to focus on positive applications of nanotechnology, to practice preventive strategies in opposition with potential risks and hazards, and to provide the necessary training to deal with the risks.

Establishment and operation of databases in nanotechnology in the field of agriculture, reinforcement of the information network, and expansion of credible educational and information culture about nanotechnology products are among the measures that can effectively familiarize people and researchers with the positive and negative consequences of this technology. In this way, confidence and trust are created in the area of nanotechnology and its applications.

REFERENCES

1. Abbasian, A.R., Chizari, M. and Bijani, M. 2017. Farmers' Views on the Factors Inhibiting the Implementation of Soil Conservation Practices (The Case of Koohdasht Township, Iran). *J. Agr. Sci. Tech. (JAST)*, **19(4):** 797-807.
2. Bijani, M. and Hayati, D. 2015. Farmers' Perceptions toward Agricultural Water Conflict: The Case of Doroodzan Dam Irrigation Network, Iran. *J. Agr. Sci. Tech. (JAST)*, **17(3):** 561-575.
3. Bond, P. J. 2003. The effects of nanotechnology on economic growth. Former Undersecretary of Commerce for Technology. United States Department of Commerce, Delivered September 9, 2003, *The World Nanoeconomic Congress*, Washington DC.
4. Cheraghi, A., Bahrani, N. and Malekfar, R. 2004. Examining the Impact of Nanotechnology on Medical and Environmental Sciences from the Nanometric Tools Perspective. *Hayat*, **10(3):** 85-94. (in Persian)
5. Council for Science and Technology. 2007. *Nanosciences and Nanotechnology: A Review of Governments Progress on its Policy Commitments.* Retrieved May 3, 2007, Available at: http://cst.Gor.uk
6. Dunmade, I. 2002. Indicators of Sustainability: Assessing the Suitability of a Foreign Technology for a Developing Economy, *Technol. Soc.*, **24(4):** 34-57.
7. Ebrahimi, R. and Chokhanizade-Moghadam, A. 2014. Take a Look at the Past and the Future Prospects for Safety Issues, Health and the Environment, Nanotechnology. *Month. Nanotechnol.*, **1(13):** 46-52. (in Persian)
8. Hayeripor, S. 2014. Guidelines Draft Environmental Impact Assessment *Tourism Projects in Marginal Water Resources (Rivers and Reservoirs of Dams).* Ministry of Power, Publication **426(2-A):** 1-5. (in Persian)
9. Krejcei, R. V. and Morgan, D. W. 1970. Determining Sample Size for Research Activities. *Edu. Psychol. Measur.*, **30:** 607-610.
10. Maghabl, R., Chizari, M. and Khayam Nekouei, M. 2011. An Investigation of the Promoter Factors of Nanotechnology

Development in Iranian Agricultural Sector. *Iran. J. Agric. Econ. Dev. Res.*, **41-2(4):** 531-539. (in Persian)
11. Majidi, F., Bijani, M. and Abbasi, E. 2017. Pathology of Scientific Articles Publishing in the Field of Agriculture as Perceived by Faculty Members and PhD. Students (The Case of Colleges of Agriculture at Public Universities, Iran). *J. Agr. Sci. Tech. (JAST),* **19(Suppl. Issue):** 1469-1484.
12. Mansourfar, K. 2006. *Advanced Statistical Methods: Using Applied Software.* University of Tehran Press. (in Persian).
13. Maynard, A.D. 2007. Nanotechnology: The Next Big Thing, or Much Ado about Nothing?. *Ann. Occup. Hyg,* **51(1):**1-12.
14. Mazaheri Asadi, M. and Gholami Qavamabad, A. 2010. Health and Environmental Hazards of Nanotechnology. *Rahbord J.*, **19(55):** 37-58. (in Persian)
15. Mirbakhsh, M., Mazaheri Asadi, M. and Gaaedniya, B. 2012. The Possible Effects of Nanoparticles on Human Health and the Environment. *The First National Conference Standard and Safety in Nanotechnology*. Iran Polymer and Petrochemical Introduction (IPPI), Tehran, Iran, 24th May 2012, (in Persian)
16. Monavari, M. 2009. *Environmental Impacts of Development Projects.* Islamic Azad University, Tehran. (in Persian)
17. Moradi, H., Bijani, M., Shabanali Fami., Fallah Haghighi, N., Tamadon, A. R. and Moradi, A. R. 2011. Analysis of Effective Components on Professional Development of Agricultural eExtension Agents in Kermanshah Province in Iran. *Int. J. Food Agric. Environ. (JFAE),* **3 and 4(9):** 803-810.
18. Mosavi, S.H. and Esmaeili, A. 2012. Self-Sufficiency Versus Free Trade: The Case of Rice in Iran. *Int Food Agribus Man,* **24(1):** 76-90.
19. Nad, R. 2005. Technology Development and Its Environmental Impacts. Quarter. J. Indust. Technol. Dev., 2(5): 36-44. (in Persian).
20. Naghdi, Y., Kaghazian, S., Mohsni fakhr, N. and Parhizi Gashti, H. 2015. Effects of Nano-Technology on Economic Growth in Selected Countries. *Quarter. J. Econ. Model,* **7(21):** 85-99. (in Persian)
21. Najafi Alamdarlo, H. 2018. The economic impact of agricultural pollutions in Iran, spatial distance function approach. *Sci Total Environ*, **616-617:** 1656-1663.
22. Norozi, N. 2014. Model Presentation for the Assessment of New Technologies. *J. Future. Res.*, 11**: 3-6.** (in Persian).
23. Poursaeed, A. R., Eshragi Samani, R. and Sharifirad, M. 2012. Experts' Attitude Regarding Usage of Nanotechnology. *Health Syst. Res.* **5(8):** 896-902. (in Persian).
24. Pratima Nikalje, A. 2015. Nanotechnology and Its Applications in Medicine. *Med. Chem.,* **5(1):** 81-89.
25. Rezaei, R., Hosseini, H., Shabanali Fami, H. and Sarafrazi, A. M. 2012. An Identification and Analysis the Mechanisms of Nanotechnology development in Iranian Agricultural Sector. *Iran. J. Agric. Econ. Dev. Res.*, **42-2(3):** 379-388. (in Persian)
26. Rezvani, M., Ramezanzadeh Lasboyee, M. and Porgaberei, M. 2010. The analysis of Socio-Economic Effects of Industrial Areas on Developing Rural Areas (Case Study: Industrial Area of Soleiman Abad, Tonekabon). *Geography Dev.*, **8(18):** 5-26. (in Persian).
27. Sabzali Parikhani, R., Sadighi, H. and Bijani, M. 2016. An Environmental Analysis of Nanotechnology in the Field of Agriculture. *2nd International Conference on Sustainable Development, Strategies and Challenges*. 23-25 February 2016, Tabriz, Iran. (in Persian)
28. Salehi, S., Chizari, M., Sadighi, H. and Bijani, M. 2017. Assessment of Agricultural Groundwater Users in Iran. A Cultural Environmental Bias. *Hydrogeol. J.*, **26(1):**285-295.
29. Shahhosseini, GH. R. 2015. The Role of Nuclear Technology in the Fields of Veterinary, Fisheries and Animal Sciences. *Scientific and Economic Status Conference on Nuclear Technology in the Development of Agricultural Areas are Holding,* Tarbiat Modares University (TMU), Tehran, Iran, February 2015, PP. 4-18. (in Persian)
30. Shatkin, J. A. 2012. Nanotechnology: Health and Environmental Risks. CRC Press.
31. Shiri, Sh., Bijani, M., Chaharsoughi Amin, H., Noori, H. and Soleymanifard, A. 2011. Effectiveness Evaluation of the Axial Plan of Wheat from Expert Supervisors' View in Ilam Province. *World Appl. Sci. J.,* **14(11):** 1724-1729.
32. Shoja Alsadati, A. and Hamedi, S. 2014. Risk Assessment of Engineered

Nanoparticles (ENPs). *J. Hazard. Sci.*, **1(1):** 37-45. (In Persian).
33. Soleimani, F., Nabipour, I., Faraji Ghasemi, F. and Dobaradaran, S. 2015. Nanoparticles Impact on Human and Environment: A Review of Toxicity, Exposure, Control Strategies, and Future Prospects. *Iran. South Med. J.*, **18(3):** 630-663. (in Persian).
34. Taqipour, M., Abbasi, E., Naeimi, A., Ganguly, S., and Zamani Miandashti, N. 2016. An investigation of self-directed learning skills among the Iranian agricultural students (Case of Agricultural College, Tarbiat Modares University). *J. Agr. Sci. Tech. (JAST)*, **18(1):** 15-26.
35. Tavakol, M. and Nozari, H. 2013. Analysis of Social, Economic and Environmental Persian Gas Refinery Industry in Rural Areas (Case Study: Rural Areas of Mohr City of Fars Province). *Quarter. Soc. Stud. Res. Iran*, **1(4):** 29-48. (in Persian).
36. Valizadeh, N., Bijani, M., and Abbasi, E. (2018). Farmers' Active Participation in Water Conservation: Insights from a Survey among Farmers in Southern Regions of West Azerbaijan Province, Iran. *J. Agr. Sci. Tech. (JAST)*, **20(5):** in press.
37. Warad, C. and Dutta, J. 2006. Nanotechnology for Agriculture and Food Systems. *J.of Nanoparticle Res.*, **5(3):** 29-38.
38. Xiaojia, H. and Huey-Min, H. 2016. Nanotechnology in Food Science: Functionality, Applicability, and Safety Assessment. *J. Food Drug Anal*, **(24):** 671-681.

پیامدهای بوم‌شناختی فناوری نانو در عرصه‌ی کشاورزی از دیدگاه پژوهشگران

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چکیده

علی‌رغم کاربردهای وسیع فناوری‌های نانو در عصر حاضر، دغدغه‌هایی پیرامون پیامدهای بوم‌زیستی آن وجود دارد. بر این اساس، هدف این پژوهش، تحلیل پیامدهای بوم‌شناختی فناوری نانو در عرصه‌ی کشاورزی بود. این تحقیق از نوع توصیفی بوده که از فن پیمایش برای جمع‌آوری داده‌ها استفاده گردید. جامعه‌ی آماری، شامل کلیه پژوهشگران و اعضای هیأت علمی مراکز و مؤسسات تحقیقات ملی کشاورزی در سراسر کشور بودند (N=190) که تعداد 123 نفر آنها با بهره‌گیری از جدول کرجسی و مورگان و روش نمونه‌گیری تصادفی طبقه‌ای با انتساب متناسب انتخاب شدند. ابزار جمع‌آوری داده‌ها، پرسشنامه‌ای بود که جهت تأیید روایی ظاهری و محتوایی، در اختیار پانلی از متخصصان ترویج و آموزش کشاورزی و تعدادی از متخصصان فعال در فناوری نانو در عرصه کشاورزی قرار داده شد. همچنین، پایایی گویه‌های سنجش پیامدهای بوم‌شناختی فناورزی نانو در کشاورزی، با استفاده از آزمون آلفای کرونباخ، مورد تأیید قرار گرفت (α= 0/78). با بهره‌گیری از تحلیل عاملی، پنج عامل به عنوان پیامدهای بوم‌شناختی فناوری نانو در عرصه کشاورزی تحت عناوین "پیامدهای اجتماعی"، "پیامدهای سلامتی ـ بهداشتی"، "پیامدهای اقتصادی"، "پیامدهای فرهنگی" و "پیامدهای زیستی" استخراج گردید که در مجموع 58/40 درصد واریانس کل را تبیین نمودند.