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Running title: A psychometric model of safety climate for vineyards

ABSTRACT

Background: This study aimed to develop a questionnaire-based tool measuring the safety climate in vineyards and to assess its psychometric properties.

Methods: A literature search was conducted to identify the dimensions and items that constitute the safety culture construct in various occupational sectors and to draft a conceptual framework. Content validity appraisal was performed by 16 farm managers or pesticide operators. The resulting preliminary conceptual framework consisted of 9 dimensions and 42 questions. Then, a telephone survey was conducted in the French Aquitaine (Bordeaux) region with 312 vineyard workers. Item-total correlation tests, Cronbach's alpha analysis and a principal component analysis were performed to confirm the unidimensionality of the scale under construction. Structural equation modelling (SEM) techniques were used to verify the model hypothesized from the exploratory analyses and to determine how well it fits the data.

Results: Exploratory analyses resulted initially in a 9-dimension, 20-item safety climate questionnaire. Internal consistency proved good with a Cronbach's alpha equal to 0.81. The SEM approach suggested two dimension groupings for a better fit of the data (7 dimensions operationalized through the same 20 items). Internal model parameters showed that the more influential dimensions of safety climate were Management commitment, Communication and feedback, Rules and practices, and Knowledge (all standardized path coefficients ≥ 0.7).

Conclusions: Owing to its good psychometric properties, we hope this score will help in drawing up relevant interventions aimed at improving safety culture, raising pesticide risk awareness, and hopefully inducing more sustainable practices in the medium-term future.

Keywords: Safety climate; Summed score; conceptual framework; management commitment; communication and feedback; rules and practices; knowledge; structural equation modeling

Abbreviation: SEM, structural equation model(ing)

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1. Introduction

Grapevines are perennial crops that suffer from a number of diseases, such as downy mildew, powdery mildew, botrytis brunch rot or black rot, which reduce grape yields. Despite efforts to select resistant grape varieties, pesticides remain the main solution used by farmers to reduce the extent of diseases. In France, winegrowing represents 4% of utilized agricultural area within the country but accounts for 14% of chemical inputs expenditure (Aubert and Enjolras, 2014).

Reducing the consumption of chemical inputs, fertilizers and pesticides has become a primary objective in France. The ambitious "Ecophyto 2018" scheme (launched in 2008) aimed at cutting pesticide use by 50% over the next decade while maintaining agricultural performance. Unfortunately, this national action plan proved over-optimistic and, instead of declining, pesticide use rose. In vineyards, the treatment frequency index (TFI - built with the normalized doses of pesticides actually applied by the wine producers) has regularly increased over the years 2006, 2010, and 2013 in all French vineyards (for example, 14.2, 14.1, 16.9 and 14.2, 15.0, 19.8, in the Bordeaux and Bourgogne vineyards, respectively) (Pujol, 2017). This trend could be explained by interannual variability in climatic conditions or parasite pressure, but also by changes in farming practices of the wine producers. A recent study showed that the effect of weather condition was moderate although significant in half of the vineyards, leaving most of the TFI variations unexplained (Pujol, 2016). A recent survey conducted in 105 French vineyards revealed that 24% of winegrowers systematically apply excessive doses of pesticides (Aubert and Enjolras, 2014). Therefore, winegrowing represents a major challenge for reducing phytosanitary treatments.

Although health problems first affect workers who handle pesticides, many vineyard farmers have been resistant to change for more sustainable practices (one must bear in mind that the spraying culture in vineyards spans a century or more), unless this change results in clear economic benefits, or they understand the importance of non-obvious long-term benefits. Changes in pest management are driven by individual (education level) and farm (size, solvency level, indebtedness, subscription of crop insurance policies) characteristics (Aubert and Enjolras, 2014). Above these change drivers, farmers placing more value on their overall health also place more value on the benefits of implementing farm safety practices (Hodne et al., 1999). Regarding pesticide safety, farmers who report experiencing adverse health problems have a higher level of pesticide risk awareness and are more likely to use alternative pest management practices than farmers who do not report having such problems (Lichtenberg and Zimmerman, 1999). Based on these observations, it can be assumed that farmers who anticipate long-term positive effects from virtuous practices have also more heightened concerns about pesticide pollution and are more familiar with safety culture principles.

The safety culture concept is easily traced back to the 1986 Chernobyl nuclear disaster in the former Soviet Union. In its aftermath, a UK nuclear safety panel developed one of the first and most commonly used definitions of safety culture: "the product of individual and group values, attitudes, perceptions, competencies and patterns of behavior that can determine the commitment to, and the style and proficiency of an organization’s health and safety management system" (Health and safety commission, 1993).

The term "safety climate" appeared earlier in the academic literature when Zohar (1980) measured workers' perceptions of work safety in various industries. He defined safety climate as a "summary molar perceptions that employees share about their work environment" and assessed it through a questionnaire whose items (questions) measured a set of 8 factors (dimensions) revealing shared perceptions. Compared to safety culture, safety climate is more applied to employee psychological characteristics, corresponding to values, attitudes and perceptions that employees have about safety in their organization (do Nascimento et al., 2017). Providing a "snapshot" of culture at a given moment in time, it can be influenced by recent events. In short, safety climate is considered the measurable aspect of safety culture (Huang et al., 2013).

The academic and scientific interest in safety climate measurement methods has resulted in a proliferation of assessment instruments, most of them based on self-assessment questionnaires, applied in different sectors, mainly in health and production areas. Specific attention to the agriculture industry (among which grape growing) has not been given and it remains unclear how these principles can be applied to this highly segmented industrial sector where similar regulations, organization structures and lines of command do not exist. In particular, long-term vineyard employees work regularly or occasionally on their own, without access to immediate support from work colleagues or managers.

Assessment of safety culture in vineyards could help understand the resistance to change and, subsequently, introduce positive attitudes and behavior towards occupational safety and health and facilitate the adoption of best practices. Therefore, this work aimed to develop a questionnaire-based tool measuring safety climate in vineyards and to assess its psychometric properties.

2. Methods

2.1. Development of the safety climate scale

2.1.1. Conceptual definition of the construct

As there is no consensus about the dimensions that make up the concept of safety culture, a literature search was conducted to identify the dimensions and items that constitute the safety culture construct in the industrial segment, armies, transport organizations or the health sector. The literature search consisted of two stages. Firstly, the 20 most cited articles published between 1980 and 2006 with the terms "safety climate", safety culture", "safety behavior" or "safety performance" in the title, abstract or keywords were extracted from the Scopus database. Among them, 8 articles were screened out because of the absence of questionnaire. A similar search strategy retrieved 11 non-redundant articles for the time period 2007-2012. As a result, a total of 23 papers were identified as being of sufficient quality and relevance to merit data extraction (Cooper and Phillips, 2004; Cox and Cheyne, 2000; Dodek et al., 2012; Fogarty and Shaw, 2010; Gershon et al., 2000; Griffin and Neal, 2000; Jliang et al., 2010; Mearns et al., 2003; Morrow et al., 2010; Neal et al., 2000; Neal and Griffin, 2006; Probst and Estrada, 2010; Raftopoulos et al., 2011; Sexton et al.,2006; Singer et al., 2007; Singer et al., 2009; Sorra and Dyer, 2010; Turnberg and Daniell, 2008; Varonen and Mattila, 2000; Vinodkumar and Bhasi, 2010; Williamson et al., 1997; Zohar, 1980; Zohar and Luria, 2005). We have, moreover, considered a Health and Safety Executive report (Davies et al., 2001), as it provides information on a number of questionnaire-based tools measuring the safety climate of organizations and offers general guidance to compile a customized survey questionnaire.

After a careful comparison of individual questionnaire dimensions, we have discarded the dimensions cited in less than 20% of questionnaires (e.g., management style, perceived supervisor competence) and those embedded in more general ones. As a result, the preliminary conceptual framework of safety climate construct was defined through the following 9 dimensions: Management commitment (managers' demonstrated value of and commitment to workers' safety), Training (process providing employees with knowledge and skills to perform their work in a safe and healthy way), Communication and feedback (interactions between employees and supervisors), Rules and best practices (specific to the activities conducted), Knowledge (specific to the activities conducted), Safety compliance (state of being in accordance with established safety standards and regulations), Safety participation (proactive orientation toward safety management and risk prevention), Teamwork climate (quality of collaboration between employees from the same work unit) and Safety system (systematic approach to managing safety, including organizational structures, accountabilities, policies and procedures).

Then, each questionnaire from the 24 documents was taken and examined item by item. Similar and identical items were grouped together. As the groupings developed, suitable labels were selected. This was not restricted to the original set of item titles where alternative labels were considered to be more appropriate. Some items were reworded or rephrased to suit vineyard working practice. In particular, to adapt the questionnaire to the agriculture sector, "company" was replaced by “farm”, “employee” by “farm worker”, “rules and procedures” by “rules and best practices”, etc. Moreover, some focus was given to pesticide exposure. As a result, the preliminary conceptual framework of the safety climate construct was based on 9 dimensions operationalized through 49 items.

2.1.2. Content validity

To assess the degree of agreement of the items in relation to the construct, content validity appraisal was performed by a team of 16 farm managers or pesticide operators working in vineyards of various acreage (from 3 to 145 hectares). They were asked to assess the degree of relevance of each item intended to measure the related construct and to check general syntax and semantic problems.

2.2. Survey administration

A telephone survey was conducted in the Aquitaine region (southwestern France) in January-February 2015 by a unique professional investigator. We used stratified random sampling to control for heterogeneity in vineyard characteristics and grape growing practices. The Bordeaux region was divided into 11 winegrowing sub-regions (strata). A sample of vineyard farms from each sub-region was randomly selected from the electronic yellow pages. Its size was proportionate to the total number of vineyard farms of the stratum. Farm managers or pesticide operators were contacted by phone during their working hours. A total of 343 eligible participants were successfully reached, of whom 312 accepted to complete the safety climate questionnaire (31 refusals).

2.3. Statistical analysis

The response to each of the items was a 5-point Likert scale (1 = disagree strongly, 2 = disagree slightly, 3 = neutral, 4 = agree slightly, 5 = agree strongly). For five negatively worded questions, reverse scores were calculated. Item scores were then summed.

Item-total correlation tests were performed to check if any item was consistent with the averaged behavior of the others. Following Devellis (2003), an item-total correlation < 0.30 indicated some factor outside of the whole scale and the corresponding item was discarded. This process was iterated until all correlations were ≥0.30. Internal consistency of the resulting set of items was measured by Cronbach’s alpha coefficient. Reliability was considered good if alpha was greater than 0.70.

A principal component analysis (PCA) was used to confirm the unidimensionality of the questionnaire by checking the items' loadings on the first component.

Structural equation modelling (SEM) techniques were used to verify the model hypothesized from the exploratory analyses and to determine how well it fits the data. The SEM consisted in an external model representing the relationships between the latent (unmeasured) variables (the dimensions or constructs) and manifest (measured) variables (their items) as well as an internal model representing the relationships between the dimensions and another latent variable, the safety climate. Standardized path coefficients were calculated, indicating the relative strength and sign of the relationships between variables while controlling for prior variables. The best fit model was assessed with the comparative fit index (CFI), the Tucker-Lewis index (TLI), the root mean square error approximation (RMSEA), and the standardized root mean square residual (SRMR). The following cutoff values were applied to assess the quality of the fit: > 0.95, > 0.95, < 0.05, and < 0.07, respectively.

All statistical analyses were performed using the Commander and lavaan packages from R software (R Development Core Team, 2018).

3. Results

3.1 Pre-testing process

The main actions taken as a result of the 16 farm managers or pesticide operators' judgment were as follows: seven questions with an insufficient degree of relevance or redundancy were removed and those presenting writing inconsistencies were accordingly changed. This content validation process resulted in the preliminary conceptual framework definition of the safety climate, consisting of 9 dimensions and 42 questions (Table 1).

3.2. Survey participants

The demographic characteristics and occupational factors for the 312 survey participants are reported in Table 2. Most respondents were male, aged over 40, had over 10 years of experience in agriculture, and were certified for pesticide application.

3.3. Reliability analysis

Because of a high rate of missing values (168 of 312), one item ("Actions taken by the agricultural cooperative aim at reducing exposure to pesticides") was removed from analyses. First-round item correlations are reported in Table 1. At this stage, the 19 items (of 41) with a corresponding coefficient <0.30 were discarded. Two further items ("Safety training given to me is adapted to the tasks I perform when handling pesticides" and "Safety regulation and good practices are adapted to work situations") were further removed in the second run of the analysis (both correlation coefficients equal to 0.28). This procedure resulted in a 9-dimension, 20-item safety climate questionnaire (grey shaded items in Table 1). Thus the total score of the scale could range from 20 to 100, a higher score reflecting a better safety climate. In this survey, the safety climate score ranked from 50 to 100 (mean: 82.9, standard deviation: 9.1).

Internal consistency of this 20-item version proved good with a Cronbach's alpha equal to 0.81. In the PCA analysis, the first component accounted for 23.4% of the total variance (while the second component explained 8.4% of the total variance), all factor loadings being positive and ranging from 0.18 to 0.29.

3.4. Confirmatory analysis

Using the SEM approach, the original structure in 9 dimensions and 20 items showed an acceptable fit to the data (CFI = 0.91, TLI = 0.90, RMSEA = 0.05, SRMR = 0.06). Path coefficients between items, dimensions and safety climate were all positive and highly significant (p values ≤ 0.0001).

However, modification indices showed that correlated error terms between Management commitment and Training dimensions, and also between Safety compliance and Safety system dimensions, were high (modification indices > 17), showing that these pairs of dimensions had something in common. As the items within these couples of latent variables were close semantically, we have slightly modified the conceptual framework by incorporating the single item from the Training dimension (“I am encouraged to attend safety training programs regularly”) into the Management commitment dimension, and the single item from the Safety system dimension (“Personal protective equipment is adapted to my work activities”) into the Safety compliance dimension. Safety participation remained as a one-item separate dimension. The SEM converged after 67 iterations. As a result, the final version of the questionnaire measuring the safety climate in vineyards is composed of 7 dimensions and 20 items (Table 3).

Figure 1 depicts the internal and external models and their standardized path coefficients. This SEM modeling fitted the data well (CFI = 0.97, TLI = 0.96, RMSEA = 0.03, SRMR = 0.05). All path coefficients remained positive and highly significant (p values ≤ 0.0001). External model parameters showed that the effects of the items on their dimension differed. For example, they varied from 0.3 to 0.6 and from 0.4 to 0.8 for the Management commitment and Safety compliance dimensions, respectively. Item effects were more homogeneous for the remaining dimensions. Internal model parameters revealed some heterogeneity regarding the impact of the 7 dimensions on the safety climate, the more influential being the Management commitment, Communication and feedback, Rules and practices, and Knowledge (all standardized path coefficients ≥ 0.7).

4. Discussion

The agriculture industry is a latecomer to the safety climate discussion. This significant gap in the field prompted us to develop and test the reliability and validity of a new instrument (7 dimensions operationalized through 20 items) designed for measuring safety climate in vineyards.

This study has several strengths. First, our approach to developing an adequate psychometric model to evaluate the safety climate in vineyards complies with the methodological principles that are recommended for research instrument modeling (do Nascimento et al., 2017). Second, using stratified random sampling made the study population as representative as possible. Evidence of construct validity provides confidence that the item measurements taken from the sample represent the true score in the vineyard-working population from the Aquitaine region. Third, the sample size and objective performance metrics used in this study strengthen the psychometric property and utility of this newly developed safety climate scale.

This research has the limitations that are inherent in studies using perceptions and self-reported response data in a cross-sectional approach. While safety culture is more stable, safety climate is subject to fluctuations in response to local variable changes and can, therefore, be seen as an organization's temporal state of safety at a discrete point in time (Huang et al., 2013). Moreover, different vineyards are likely to have different managerial styles, attitudes towards safety issues, and levels of quality of the supervisor–employee relationship, inducing some heterogeneity. Criterion validity of the score could not be established because of the lack of safety behavior data that would have required ethnographic approaches based on observation and interview. Finally, we were also not able to set score limits to distinguish between performance levels and identify specific vineyards with low levels of safety climate to guide the implementation of strategies to improve safety culture.

A safety climate measurement tool suited for the vine-growing industry had not been introduced before the current study to the best of our knowledge. As Zohar suggested (2010), development of industry-specific climate scales should be encouraged as it is likely to identify new, context-dependent targets of climate perception in respective industries. We built our conceptual framework without any assumption on the number and composition of dimensions and their underlying causal structure. As all items predicted their corresponding dimensions (p values ≤ 0.0001) at the outset, no model-trimming was required. Only some fine-tuning was performed, based on the modification indexes to achieve better fit, as it made sense semantically.

This new safety climate scale has been validated as a whole. Item groupings (or dimensions) were only indicative although helpful in the identification of a core safety climate item set and the confirmatory analysis. For these reasons, we discourage any dimension sub-scoring, all the more as the number of items per dimension is small, ranging from one to six.

Not surprisingly, the safety management practice dimensions (Management commitment, Communication and feedback, Rules and best practices), as well as the Knowledge dimension (a determinant of safety performance), turned out to have the most impact (Flin et al., 2006). The components of safety performance (Safety compliance and Safety participation) rank lower, suggesting that organization governance was considered more influential than individual behaviors on safety climate. Finally, the lowest impact of the teamwork climate dimension may be related to the lone working that characterizes a number of vineyard tasks. Therefore, expectations of work-related social support could be moderate and, at least, not considered to heavily influence the safety climate in these mainly individual practices. Further research across vineyards located in various countries would be useful in interpreting more accurately the core constructs of this new safety climate instrument.

5. Conclusion

The practical and theoretical significance of safety climate as a construct stems from its ability to predict safety behavior and safety-related outcome (here in the sense of lower pesticide use rather than fewer worker injuries) (Huang et al., 2013). It is hoped that the safety climate tool assessed in this study will help researchers, occupational health experts and vineyard managers in drawing up relevant interventions aimed at improving safety culture, raising pesticide risk awareness, and hopefully inducing more sustainable practices in the medium-term future.

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The authors declare no conflicts of interest.

Authors' contributions

SG generated the idea for the paper and supervised the fieldwork and data collection. JFV conducted the statistical analyses. SG and JFV wrote and approved the final manuscript.

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Table 1
Conceptual framework of the safety climate and first-round item-total correlations (N=312).

Dimensions (construct)	Indicators	Item-total correlation
Management commitment	MC1 Pesticide safety is given a high priority by farm management	0.48
	MC2 Actions are undertaken to reduce pesticide exposure in the farm	0.38
	MC3 Farm management strives to reduce pesticide exposure in farmworkers	0.28
	MC4 Actions taken by the agricultural cooperative aim at reducing exposure to pesticides[a]	NA
	MC5 Actions taken by health promoters aim at reducing exposure to pesticides	0.33
	MC6 I have been consulted about safety issues when using pesticides	0.39
	MC7 I am encouraged to become involved in pesticide safety matters	0.36
	MC8 I trust the expertise of the people in charge of health risk reductions of pesticide use	0.26
Training	T1 Safety training given to me is adequate to identify and estimate health risks of pesticide use	0.29
	T2 Safety training given to me is adapted to the tasks I perform when handling pesticides[b]	0.30
	T3 I am encouraged to attend safety training programs regularly	0.32
Communication & feedback	CF1 There is open and easy communication between health organizations	0.28
	CF2 I know the incident reporting system of health organizations	0.39
	CF3 There is open and easy communication with other farm managers/workers	0.24
	CF4 There is open and easy communication with my managers and co-workers	0.29
	CF5 I am encouraged to report any safety matters to improve my protection during pesticide use	0.32
	CF6 After an incident during pesticide handling, I have made /I will make improvements	0.44
Rules & best practices	RP1 I perceive safety regulation as binding[c]	0.22
	RP2 I perceive good safety practices as binding[c]	0.18
	RP3 Safety regulation and good practices are useful to prevent risk	0.33
	RP4 Safety regulation and good practices are adapted to work situations[b]	0.32
	RP5 I attach particular importance to the maintenance of work area, equipment and machinery	0.32
Knowledge	K1 I believe that I take risks when handling pesticides during my work activities	0.08
	K2 I know when to use personal protective equipment	0.34
	K3 I know safety regulation	0.35
	K4 I have a "zero incident" goal	0.36
	K5 It is likely that I will be involved in an incident	0.03
Safety compliance	SC1 I use all necessary safety equipment to do my job.	0.47
	SC2 I respect good practices that protect me from pesticide exposure	0.44
	SC3 I think I have unsafe work practices[c]	0.07
Safety participation	SP1 I put in extra effort to improve my safety when using pesticides	0.37
	SP2 I participate in working groups to improve my safety when using pesticides	0.17
	SP3 It is important to reduce my exposure to pesticides	0.26
Teamwork climate	TW1 I feel that there is loss of information between co-workers on my farm[c]	0.08
	TW2 My co-workers share the same concerns as me about workplace health	0.38
	TW3 My co-workers comply with good practices	0.40
	TW4 The other farmers I know share the same concerns as me about workplace health	0.23
	TW5 The other farmers I know comply with good practices	0.26
Safety system	SS1 Economic pressure is too strong to make safety my priority[c]	0.28
	SS2 Personal protective equipment is readily available	0.25
	SS3 Personal protective equipment is adapted to my work activities	0.36
	SS4 Farm spraying equipment (tractor sprayer equipment) protects me from pesticide exposure	0.27

Grey-shaded items are included in the final safety climate questionnaire
[a] not considered in the reliability analysis because of 168 missing values
[b] discarded after the second round of item-total correlations
[c] reverse-scored item

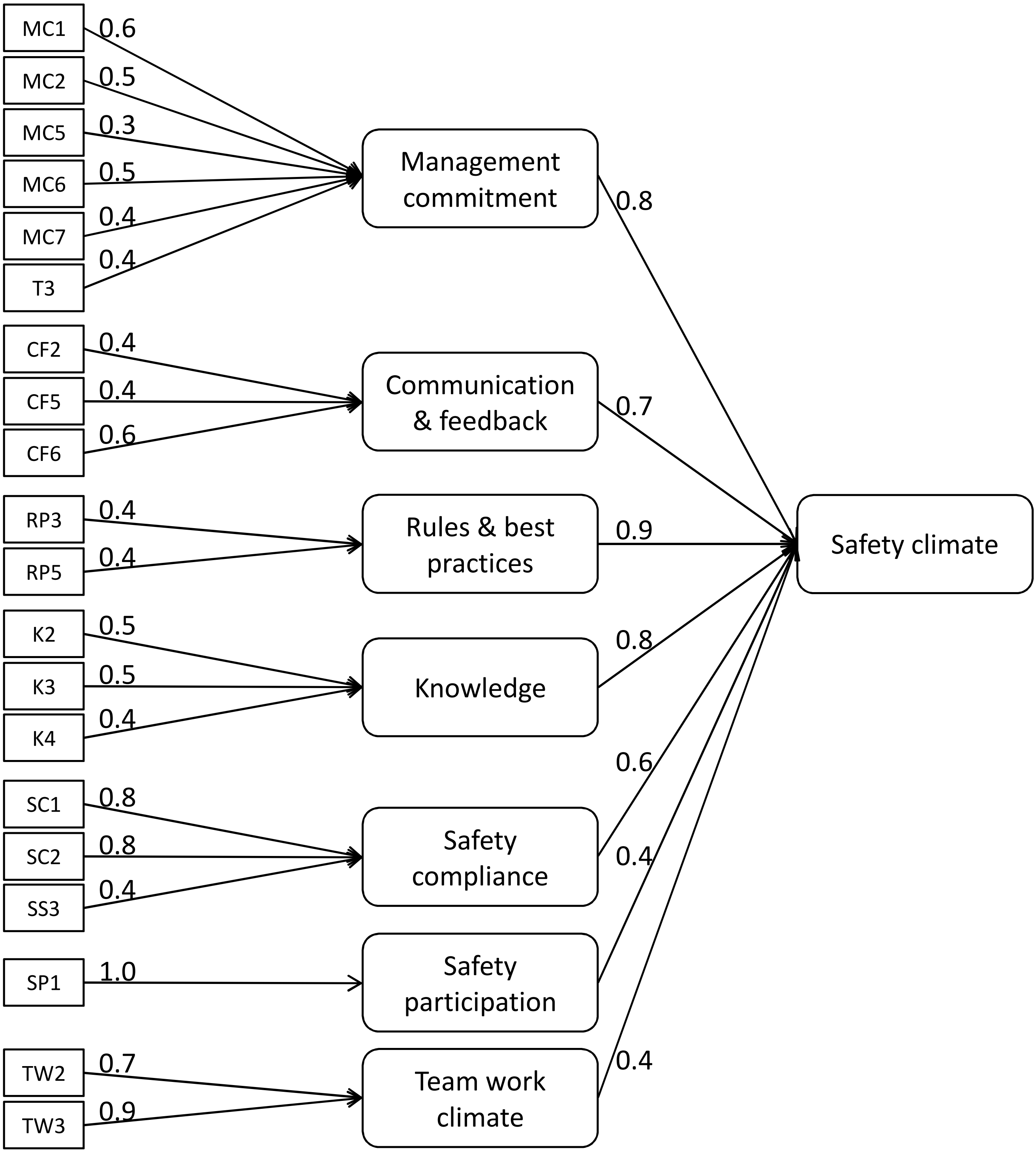
Table 2
Characteristics of the participants in the safety climate survey (N=312).

Gender	
Female	20 (6.4)
Male	292 (93.6)
Age (years)	
< 40	60 (19.3)
40 – 49	96 (30.8)
50 – 59	97 (31.0)
≥ 60	59 (18.9)
Experience in agriculture (years)	
< 10	15 (4.8)
10 – 19	64 (20.5)
20 – 29	95 (30.5)
30 – 39	86 (27.5)
≥ 40	52 (6.7)
Position	
Farm worker	13 (4.2)
Farmer / farm manager	299 (95.8)
Pesticide applicator certificate	
No	32 (10.3)
Yes	280 (89.7)
Pesticide-related activities	
Preparation	
No	46 (14.7)
Yes	266 (85.3)
Application	
No	48 (15.4)
Yes	264 (84.6)
Equipment cleaning	
No	48 (15.4)
Yes	264 (84.6)

Table 3
Final version of the questionnaire measuring safety climate for vineyards.

Dimensions	Items
Management commitment	Pesticide safety is given a high priority by farm management
	Actions are undertaken to reduce pesticide exposure in the farm
	Actions taken by health promoters aim at reducing exposure to pesticides
	I have been consulted about safety issues when using pesticides
	I am encouraged to become involved in pesticide safety matters
	I am encouraged to attend safety training programs regularly
Communication & feedback	I know the incident reporting system to health organizations
	I am encouraged to report any safety matters to improve my protection during pesticide use
	After an incident during pesticide handling, I have made / will make improvements
Rules and best practices	Safety regulation and good practices are useful to prevent risk
	I attach particular importance to the maintenance of work area, equipment and machinery
Knowledge	I know when to use personal protective equipment
	I know safety regulation
	I have a "zero incident" goal
Safety compliance	I use all necessary safety equipment to do my job.
	I respect good practices that protect me from pesticide exposure
	Personal protective equipment is adapted to my work activities
Safety participation	I put in extra effort to improve my safety when using pesticides
Teamwork climate	My co-workers share the same concerns as me about workplace health
	My co-workers comply with good practices

Fig. 1. Final structural equation model with standardized path coefficients (all p values ≤ 0.0001, covariances have been omitted).



MC: management commitment, T: training, CF: communication & feedback, RP: rules & best practices, K: knowledge, SC: safety compliance, SS: safety system, SP: safety participation, TW: teamwork climate