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Intention to adopt climate-resilient agricultural practices among wheat farmers in Punjab, Pakistan: an extended Theory of Planned Behaviour

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ABSTRACT: This study aimed to investigate the psychosocial determinants of wheat growers' intention to adopt a specific set of climate-resilient agricultural practices (CRAPs) in the Punjab Province of Pakistan, which is an extended Theory of Planned Behaviour (TPB) including attitude, subjective norms, perceived behavioural control, trust in CRAPs performance, and current climate-resilient practice management (past behaviour). In May–July 2024, a cross-sectional survey of 384 wheat growers was carried out involving a six-stage design, purposively sampled agro-ecological zones, districts, tehsils, and randomly sampled union councils, villages, and growers. The five CRAPs were conservation tillage, certified heat- and drought-tolerant varieties, timely sowing, stage-based balanced fertilisation and critical-stage irrigation. Partial least squares structural equation modelling (PLS-SEM) was used for data analysis with 10,000 subsamples generated by bootstrapping. Attitude was the strongest positive predictor of intention ($\beta = 0.446$; 95% CI 0.319–0.543; $p < 0.001$), followed by trust in CRAPs performance ($\beta = 0.344$; $p < 0.001$) and perceived behavioural control ($\beta = 0.172$; $p = 0.001$). Subjective norms were not significant ($\beta = 0.038$; $p = 0.455$). Despite a positive bivariate correlation with intention, current CRAP management had a negative partial coefficient ($\beta = -0.246$; $p < 0.001$). This is a pattern of statistical suppression or a "ceiling effect," not a pattern of resistance to change. The model explained 48.6% of the variance in intention (adjusted $R^2 = 0.479$; $Q^2predict = 0.389$). The cross-sectional and intention-based nature of the design means that the results refer to intention and not actual adoption. They propose that extension programmes can reinforce intention by showing growers the agronomic success of CRAPs and help them develop the capacity to adopt them.
Keywords: *Triticum aestivum* L.; climate change adaptation; reasoned action approach; PLS-SEM; agricultural extension; smallholder farmers.

Intenção de adoção de práticas agrícolas resilientes ao clima por produtores de trigo em Punjab, Paquistão: uma Teoria do Comportamento Planejado estendida

RESUMO: Este estudo teve como objetivo investigar os determinantes psicossociais da intenção de produtores de trigo de adotar um conjunto específico de práticas agrícolas resilientes ao clima (CRAPs, na sigla em inglês) na província de Punjab, no Paquistão. A abordagem baseou-se em uma extensão da Teoria do Comportamento Planejado (TCP), incluindo os seguintes construtos: atitude, normas subjetivas, controle comportamental percebido, confiança no desempenho das CRAPs e o manejo atual de práticas resilientes ao clima (comportamento passado). Entre maio e julho de 2024, realizou-se um estudo transversal com 384 produtores de trigo, utilizando um delineamento em seis estágios: seleção intencional de zonas agroecológicas, distritos e *tehsils* (subdivisões distritais), seguida de amostragem aleatória de *union councils* (unidades administrativas locais), vilarejos e produtores. As cinco CRAPs analisadas foram: cultivo conservacionista, uso de variedades certificadas tolerantes ao calor e à seca, semeadura na época adequada, fertilização balanceada por estágios de desenvolvimento da cultura e irrigação nas fases críticas. Para a análise dos dados,

utilizou-se a modelagem de equações estruturais por mínimos quadrados parciais (PLS-SEM), com 10.000 subamostras geradas por meio de bootstrapping. A atitude foi o preditor positivo mais forte da intenção (β = 0,446; IC 95% 0,319–0,543; p < 0,001), seguida pela confiança no desempenho das CRAPs (β = 0,344; p < 0,001) e pelo controle comportamental percebido (β = 0,172; p = 0,001). As normas subjetivas não apresentaram significância estatística (β = 0,038; p = 0,455). Apesar de haver correlação bivariada positiva com a intenção, o manejo atual de CRAPs apresentou um coeficiente parcial negativo (β = −0,246; p < 0,001). Esse resultado reflete um padrão de supressão estatística ou um "efeito teto", e não uma resistência à mudança. O modelo explicou 48,6% da variância na intenção (R^2 ajustado = 0,479; Q^2predict = 0,389). Dada a natureza transversal e o foco na intenção, os resultados referem-se à intenção de adoção, e não à adoção efetiva das práticas. Eles propõem que programas de extensão reforcem a intenção ao demonstrar aos produtores o sucesso agronômico das práticas agrícolas resilientes ao clima (CRAPs) e auxiliá-los a desenvolver a capacidade de adotá-las.

Palavras-chave: *Triticum aestivum* L.; adaptação às mudanças climáticas; abordagem da ação fundamentada; PLS-SEM; extensão agrícola; pequenos agricultores.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the key cereal crop and the main source of food in Pakistan and plays a vital role in the food security of the country and in the livelihood of millions of farmers' families, with the majority in Punjab province (ALI; ERENSTEIN, 2017; GOP, 2023). In Pakistan, wheat is cultivated in the rabi season and is vulnerable to multiple reported climate hazards such as increases in temperature and terminal heat during grain filling, variability in winter monsoon rainfall, drought in early spring and reduced availability of canal water (ABID et al., 2015; AHMAD et al., 2022; IPCC, 2022). The agro-ecological diversity in Pakistan and farm-level resource limitations are the key factors that limit the adaptive capacity of Pakistan (FAHAD; WANG, 2018; NADEEM et al., 2024).

The Punjab Agriculture Department, as well as climate-smart agriculture programmes (Lipper et al., 2014; FAO, 2021), encourage several practices at the farm level that can mitigate the susceptibility of wheat to these hazards. They include using conservation (reduced or zero) tillage, using certified heat- or drought-tolerant varieties, sowing within the recommended window, and stage-based balanced fertilisation and irrigation scheduled for critical growth stages. Nevertheless, the adoption of these practices among wheat growers in Pakistan is incomplete and lacking in uniformity, and there is a disconnect between the recommended and implemented practices (ABID et al., 2015; ALI; ERENSTEIN, 2017; FAHAD; WANG, 2018). In a survey of irrigated Punjab rice–wheat growers (458), only 19% had adopted zero-till wheat (FAROOQ et al., 2007).

Climate adaptation studies in Pakistan have mostly focused on socio-economic and agronomic correlates of adaptation, including farm size, education, credit, extension contact and access to irrigation (ABID et al., 2015; ALI; ERENSTEIN, 2017; FAHAD; WANG, 2018). Little is known about the psychosocial antecedents of growers' decisions, which would involve how growers value CRAPs, their social expectations and their self-judgement of their ability to manage CRAPs.

The Theory of Planned Behaviour (TPB) offers a parsimonious framework for these antecedents and has been widely applied to farmers' conservation and sustainability decisions (AJZEN, 1991; BEEDELL; REHMAN, 2000; WAUTERS et al., 2010; BORGES et al., 2014; SOK et al., 2021). Despite the benefits, uptake of climate-resilient or climate-smart practices in South Asia, especially in wheat systems in Pakistan, is still limited (SOK et al., 2021; ATTA-AIDOO et al., 2022).

The TPB is specifically stated to be open to other predictors that explain variance in intention not explained by attitude, norms and control (AJZEN, 1991; CONNER; ARMITAGE, 1998). There are two extensions applicable for CRAPSs. The first is about confidence in the workings of the practice. CRAPSs are frequently like innovations of credence, for which the benefits are uncertain, delayed and depend on the weather. A grower can have a favourable attitude (control) towards a practice but still not believe that it will be useful in his/her own field (MAYER et al., 1995; MEIJER et al., 2015; SIEGRIST, 2021). The second is past behaviour, here operationalised as the level of adoption of the CRAPS recommendations by growers for their wheat. One of the most common TPB extensions tests is past behaviour, as past behaviour and previous experience can predict intention above and beyond the core constructs (OUELLETTE; WOOD, 1998; CONNER; ARMITAGE, 1998; AJZEN, 2011). But it is unclear when the behaviour of interest is already somewhat implemented. There is no published study that simultaneously tried both the extensions for climate-resilient wheat practices in Pakistan, to our knowledge.

This study contributes, therefore, in three ways. First, it clearly specifies the target behaviour as a set of five agronomic CRAPs, thereby overcoming a common pitfall in adoption studies using less well-defined “climate-smart” behaviours. Second, it examines whether trust in CRAPs performance and current CRAPs management provide explanatory and predictive value for the core TPB, and whether the extended model can be evaluated with effect sizes, out-of-sample prediction and robustness checks, in addition to path significance. Third, it addresses the issue of how this relationship between intentions and antecedents is shaped by prior partial adoption by growers and has implications for extension programmes that focus on growers already using some CRAPs. The goal of this study was to explore the psychosocial factors explaining wheat farmers' reported willingness to adopt the CRAPs bundle in Punjab. The study does not measure - and makes no conclusions about - subsequent adoption behaviour.

2. FRAMEWORK AND HYPOTHESES

Figure 1 presents the extended TPB model. In the TPB, intention is the proximal antecedent of behaviour and summarises a person's motivation and planned effort to

perform it (AJZEN, 1991; FISHBEIN; AJZEN, 2010). Here, intention refers to the grower's plan and commitment to implement the CRAPs bundle on his wheat crop in the coming seasons.

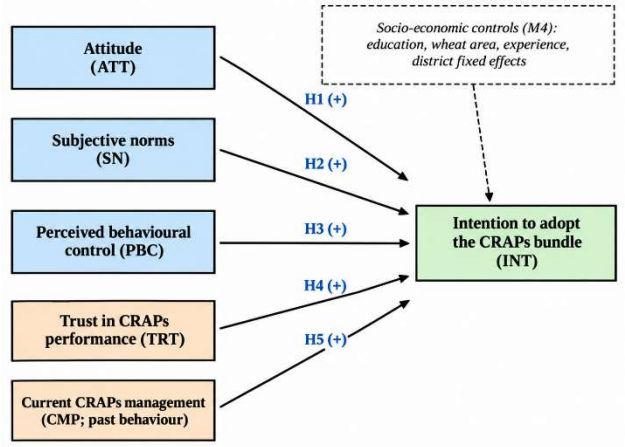


Figure 1. Extended Theory of Planned Behaviour model of wheat growers' intention to adopt the climate-resilient agricultural practice (CRAPs) bundle. Blue boxes are core TPB constructs and orange boxes are the extension constructs. Arrows show hypotheses H1–H5 and their expected signs. Socio-economic controls (dashed box) are included in the robustness analysis.

Figura 1. Modelo estendido da Teoria do Comportamento Planejado (TCP) sobre a intenção dos produtores de trigo de adotar o conjunto de práticas resilientes ao clima (PRC). Os quadros em azul representam os constructos centrais da TCP, enquanto os quadros em laranja representam os constructos da extensão do modelo. As setas indicam as hipóteses H1–H5 e seus respectivos sinais esperados. Variáveis de controle socioeconômicas (quadro com borda tracejada) são incluídas na análise de robustez.

2.1. Attitude (H1)

Attitude is the grower's overall evaluation of implementing CRAPs as beneficial or harmful, advantageous or disadvantageous, and desirable or undesirable (AJZEN, 1991). Meta-analytic evidence shows that attitude is usually the strongest TPB predictor of intention (ARMITAGE; CONNER, 2001). Among farmers, positive evaluations of conservation and climate-smart practices are consistently associated with stronger adoption intentions (WAUTERS et al., 2010; LALANI et al., 2016; SOK et al., 2021; ATTA-AIDOO et al., 2022).

H1: Attitude towards CRAPs is positively associated with wheat growers' intention to adopt CRAPs.

2.2. Subjective norms (H2)

Subjective norms are the perceived social pressure from important referents, such as fellow farmers, family and community members, to perform or not perform the behaviour (AJZEN, 1991). In village settings, approval by neighbouring and lead farmers is expected to strengthen intention (VILLAMAYOR-TOMAS et al., 2021; ATTA-AIDOO et al., 2022). Evidence across farm studies is nevertheless mixed, and norms are often the weakest TPB predictor (ARMITAGE; CONNER, 2001; SOK et al., 2021).

H2: Subjective norms regarding CRAPs are positively associated with wheat growers' intention to adopt CRAPs.

2.3. Perceived behavioural control (H3)

Perceived behavioural control (PBC) is the perceived ease or difficulty of performing the behaviour. It covers both self-efficacy (confidence in one's ability) and perceived controllability (access to time, information and resources) (AJZEN, 2002). Growers who feel able to implement CRAPSs and who can obtain the necessary advice are expected to report stronger intentions (WANG et al., 2020; ATTA-AIDOO et al., 2022).

H3: Perceived behavioural control over CRAPs is positively associated with wheat growers' intention to adopt CRAPs.

2.4. Trust in CRAPS performance (H4)

Trust is a willingness to rely on a referent under uncertainty, based on expectations of its competence and reliability (MAYER et al., 1995). The referent here is the technology itself: the grower's confidence that CRAPs will perform reliably and deliver the promised productivity and time benefits on his farm (MCKNIGHT et al., 2011). This construct differs from institutional trust, which concerns extension agents or government programmes and was not measured in this study. It also differs from PBC, which concerns the grower's own capability. Trust in a technology reduces the perceived risk of trying it and is associated with adoption of agricultural innovations (MEIJER et al., 2015; SIEGRIST, 2021). It can contribute beyond attitude because a practice may be judged desirable in general yet be doubted at field level.

H4: Trust in CRAPs performance is positively associated with wheat growers' intention to adopt CRAPs.

2.5. Current CRAPs management (past behaviour) (H5)

The management items ask whether growers already prepare land, select varieties, sow, fertilise and irrigate according to CRAPs recommendations. They therefore measure current or past implementation of the CRAPs components, that is, past behaviour, and not resistance to change or attachment to traditional practices. In the TPB literature, past behaviour usually predicts intention positively, because experience strengthens habits and makes intentions more stable (CONNER; ARMITAGE, 1998; OUELLETTE; WOOD, 1998; AJZEN, 2011). Past behaviour is placed as an antecedent of intention because the items describe practices already used in previous seasons, whereas intention concerns future seasons.

H5: Current CRAPs management (past behaviour) is positively associated with wheat growers' intention to adopt CRAPs.

3. MATERIAL AND METHODS

3.1. Study design

A cross-sectional household survey was conducted with wheat growers in Punjab, Pakistan. Data were collected through face-to-face structured interviews between 15 May 2024 and 30 July 2024, after the 2023–24 rabi wheat season. The study is reported following the recommendations of Hair et al. (2019) for PLS-SEM studies.

3.2. Study area

Punjab is Pakistan's most populous province and its main agricultural province. It covers about 205,000 km² between approximately 27.7° and 34.0° N latitude and 69.3° and 75.4°

E longitude. In terms of wheat area, the share of Punjab is highest in the country, followed by Sindh and Khyber Pakhtunkhwa provinces, while in the case of wheat production, the province of Punjab has the largest share, followed by Khyber Pakhtunkhwa and Sindh provinces (GOP, 2023; GOP, 2024). The province consists mainly of irrigated plains and a semi-arid to arid subtropical climate. The annual rainfall varies from less than 200 mm in the southwest to more than 1000 mm in the northeast sub-montane belt. In Pakistan, there are ten agro-ecological zones (PARC, 2024). Punjab is predominantly located in the Northern Irrigated Plain, Sandy Desert (Thal), Barani (rain-fed) Lands, Sulaiman Piedmont and the northern portion of the Southern Irrigated Plain. The three zones sampled and the districts and tehsils in each zone are included in the mapping (Figure 2) and in the listing (Table 1).

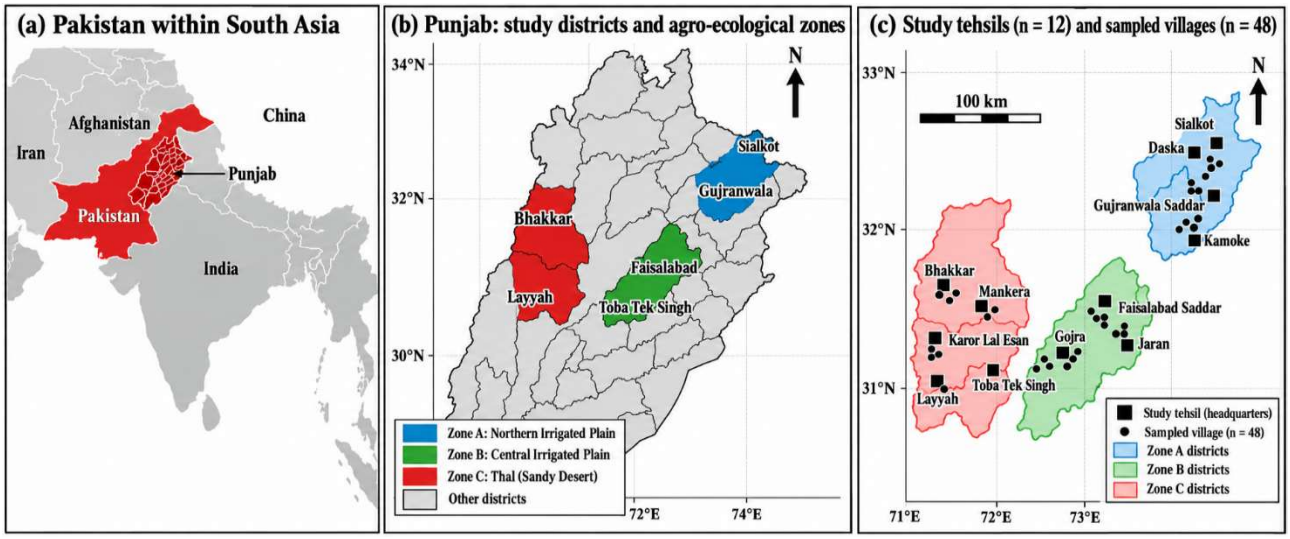


Figure 2. Location of the study area. (a) Pakistan within South Asia; (b) Punjab province and its districts, with the six study districts highlighted and the three agro-ecological zones shaded; (c) the twelve study tehsils and the 48 sampled villages. Each panel includes a graticule (latitude/longitude), a scale bar and a north arrow; datum WGS 84. Boundary source: OCHA–HDX Pakistan Subnational Administrative Boundaries and GADM v4.1 (datum WGS 84).

Figura 2. Localização da área de estudo. (a) Paquistão no contexto do Sul da Ásia; (b) província de Punjab e seus distritos, com os seis distritos de estudo em destaque e as três zonas agroecológicas sombreadas; (c) os doze tehsils (subdistritos) de estudo e as 48 vilas amostradas. Cada painel inclui uma grade de coordenadas (latitude/longitude), uma barra de escala e uma seta indicando o norte; datum WGS 84. Fonte dos limites: OCHA–HDX (Limites Administrativos Subnacionais do Paquistão) e GADM v4.1 (datum WGS 84).

Table 1. Sampling frame and selection criteria at each stage.
Tabela 1. Estrutura amostral e critérios de seleção em cada etapa.

Stage	Unit (number selected)	Selection	Units and criterion
1	Agro-ecological zone (3)	Purposive	Northern Irrigated Plain (Zone A), Central Irrigated Plain (Zone B) and Thal Sandy Desert (Zone C): chosen to cover contrasting topography and water regimes (irrigated plain, sandy desert and rain-fed) and high wheat area
2	District (6; 2 per zone)	Purposive	Gujranwala and Sialkot (Zone A); Faisalabad and Toba Tek Singh (Zone B); Bhakkar and Layyah (Zone C): the two districts with the largest wheat area in each zone (Crop Reporting Service, Punjab, 2022–23)
3	Tehsil (12; 2 per district)	Purposive	Gujranwala Saddar and Kamoke; Sialkot and Daska; Faisalabad Saddar and Jaranwala; Toba Tek Singh and Gojra; Bhakkar and Mankera; Layyah and Karor Lal Esan: the two tehsils with the largest wheat area in each district
4	Union council (24; 2 per tehsil)	Simple random	Drawn from the official list of union councils in each tehsil
5	Village (48; 2 per union council)	Simple random	Drawn from the list of revenue villages in each union council
6	Wheat grower (384; 8 per village)	Simple random (lottery)	Drawn from village lists of wheat growers compiled with the village Agriculture Officer/lambardar (frame verified with the Crop Reporting Service, Punjab)

3.2. Population, eligibility and sampling

Wheat growers of the 12 study tehsils were the target population. In 2023, an estimated 118,400 households cultivated wheat in the area (Crop Reporting Service, Punjab 2023). The main decision-maker of wheat in the household, aged≥ 18 and having grown wheat in the last season either on own or rented land, was considered an eligible respondent. If a grower was not growing wheat and the member of a household had been interviewed before, they were not interviewed again. The design was a six-stage one (Table 1; Figure 3). The first three stages were purposive. The sample should not be generalised to cover all wheat growers of Punjab or Pakistan; however, it can be considered to represent the growers of high wheat tehsils of the three zones studied. Eligible growers were numbered on the village list, and 8 growers were selected by lottery in each village. Any grower who did not show at the second of two visits or who refused was replaced with the next numbered grower. A total

of 452 growers were approached, 31 growers refused, 26 were not available, and 11 interviews were incomplete, leaving 384 completed interviews (a response rate of 85.0) (Figure 3).

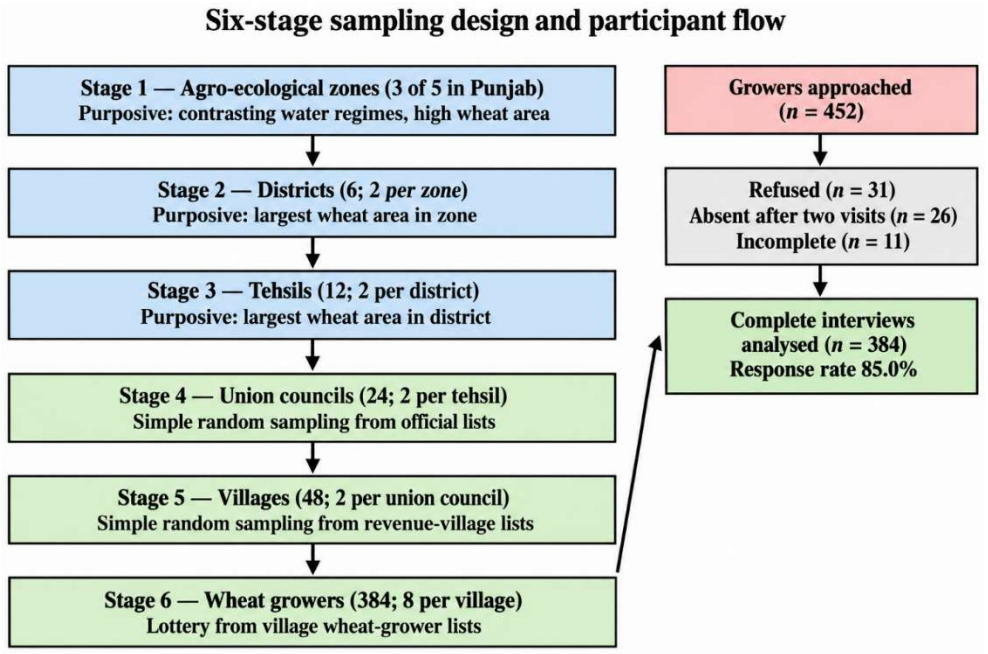


Figure 3. Multistage sampling design and participant flow. Blue boxes show purposive stages and green boxes show random stages.
Figura 3. Desenho de amostragem em múltiplos estágios e fluxo de participantes. Os quadros azuis indicam estágios intencionais, e os verdes, estágios aleatórios.

3.3. Sample size and statistical power

The large population (N ≥ 100,000) target of 384 respondents was derived from Krejcie; Morgan (1970), which assumes a 95% level of confidence, ±5% margin of error, and 0.5 as the p-value.

Since this is a rule for estimating a proportion, the appropriateness of n = 384 for the structural model was also evaluated in three ways (Table 2; Figure 4). By the inverse square-root method (Kock; Hadaya, 2018), for α = 0.05, and for detection of the smallest path judged to be of practical interest (|β| = 0.172), it takes at least n ≥ 210 observations.

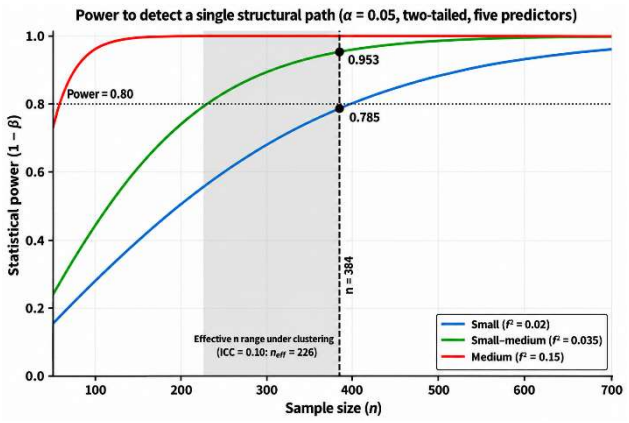


Figure 4. Statistical power to detect a single structural path in a model with five predictors (α = 0.05, two-tailed) as a function of sample size, for small (f^2 = 0.02), small-to-medium (f^2 = 0.035) and medium (f^2 = 0.15) effects. The vertical line marks n = 384. The shaded band spans the effective sample size under within-village clustering (ICC = 0.10, n_eff = 226) up to n = 384.
Figura 4. Poder estatístico para detectar um único caminho estrutural em um modelo com cinco preditores (α = 0,05, bicaudal) em função do tamanho da amostra, para efeitos pequenos (f^2 = 0,02), pequenos a médios (f^2 = 0,035) e médios (f^2 = 0,15). A linha vertical marca n = 384. A faixa sombreada abrange desde o tamanho efetivo da amostra sob agrupamento em vilas (ICC = 0,10, n_eff = 226) até n = 384.

Second, an a priori power analysis for a single path in a model with five predictors (F-test, α = 0.05; Faul et al., 2009) showed power of 0.953 for f^2 = 0.035 and 0.785 for a small effect (f^2 = 0.02).

Thirdly, growers are grouped per village (8 growers per village). Thus, the design effect was estimated as DEFF = 1 + (m − 1) × ICC (m = 8). The intra-class correlation of 0.10 results in an effective sample size of 226, which is still larger than the inverse square-root minimum.

The ICC of intention across villages was observed to be 0.049 (see Robustness analysis). The sample size was thus sufficient for small to moderate effects. Thus, effects as small as |β| ≈ 0.04 would require approximately 4,282 respondents, and the non-significance of the effect should not be interpreted as a lack of effect.

3.4. Definition of the target behaviour

The desired behaviour was for the grower to implement a package of five CRAPSs on their wheat crop. Selection of each practice was based on the recommendation of the Punjab Agriculture Department for wheat crops and the fact that these practices are proven to decrease sensitivity of wheat to heat, water stress and erratic rainfall (Table 3). Each of the five components is related to each of the five operations listed in the management items (Table 4), to which every respondent was questioned in the same wording. As a result, the same set of practices was evaluated by all the respondents.

There were three reasons why the bundle was treated as one target behaviour: the 5 practices are recommended and promoted as a package, these practices are implemented in sequence during the same crop cycle, and the questionnaire

was written to refer to "climate-resilient practices" as a group. We recognize that growers may wish to implement some, but not all of the components. This restriction is addressed in the subsequent discussion, and future intentions on a component basis are suggested.

Table 2. Sample-size adequacy and statistical power for the structural model (computed for this revision).
Tabela 2. Adequação do tamanho da amostra e poder estatístico para o modelo estrutural (calculados para esta revisão).

Criterion	Value	Implication for n = 384
Krejcie and Morgan (1970), N ≥ 100,000, 95% CL, ±5%	n = 384	Meets the target for a proportion estimate
Inverse square-root method, |β|min = 0.172, α = 0.05	n ≥ 210	Adequate
Inverse square-root method, |β| = 0.038 (SN path)	n ≥ 4,282	Underpowered to detect an effect this small
Power, single path, 5 predictors, f^2 = 0.02	0.785	Close to the 0.80 benchmark
Power, single path, 5 predictors, f^2 = 0.035	0.953	Adequate
Power, overall R^2, 5 predictors, f^2 = 0.035	0.815	Adequate
Design effect, m = 8, ICC = 0.05 / 0.10 / 0.15	1.35 / 1.70 / 2.05	Effective n = 284 / 226 / 187

Table 3. Operational definition of the climate-resilient agricultural practice (CRAPs) bundle presented to respondents.
Tabela 3. Definição operacional do conjunto de práticas resilientes ao clima (PRC) apresentado aos respondentes.

CRAPS component	Operational definition (examples)	Climate-resilience rationale
Conservation tillage	Reduced or zero tillage (e.g., zero-till drill or Happy Seeder after rice) with residue retention, and/or laser land levelling before sowing	Conserves soil moisture, advances sowing and reduces exposure to terminal heat (Lipper et al., 2014)
Resilient varieties	Certified, approved heat- and drought-tolerant wheat varieties recommended for the zone	Tolerance to terminal heat and water deficit (Ahmad et al., 2022)
Timely sowing	Sowing within the zone's recommended sowing window	Avoids heat stress during grain filling (Abid et al., 2015)
Stage-based balanced fertilisation	Recommended N–P–K doses, with N split by crop stage	Improves nutrient-use efficiency under variable rainfall
Critical-stage irrigation	Irrigation scheduled to critical stages (crown-root initiation, booting, grain filling)	Limits yield loss under canal-water shortages

Note: The examples in the second column illustrate each operation; the questionnaire items referred to each operation as performed "according to climate-resilient practices".
Nota: Os exemplos na segunda coluna ilustram cada operação; os itens do questionário referiam-se a cada operação como sendo realizada "de acordo com práticas resilientes ao clima".

Table 4. Measurement items, construct definitions and status in the revised model.
Tabela 4. Itens de mensuração, definições de construtos e status no modelo revisado.

Code	Item (5-point Likert, 1 = strongly disagree … 5 = strongly agree)	Specification	Status
INT1	I intend to adopt CRAPSs on my wheat crop in the future because they are more useful than conventional technologies.	Reflective	Removed (contains attitude content)
INT2	I am committed to making efforts to use CRAPSs on my wheat crop to reduce the impacts of climate change.	Reflective	Retained
INT3	I intend to invest time in learning about CRAPSs for my wheat-farming	Reflective	Retained
INT4	In my view, CRAPSs are better than the traditional method of growing wheat.	Reflective	Removed (attitude
INT5	I expect to seek more guidance on implementing CRAPSs on my wheat fields in future.	Reflective	Removed (guidance-seeking)
CMP1	I prepare land for wheat according to CRAPS recommendations.	Formative	Retained
CMP2	I select wheat varieties according to CRAPS recommendations.	Formative	Retained
CMP3	I sow my wheat on time in accordance with CRAPS recommendations.	Formative	Retained
CMP4	I apply fertilisers on time following CRAPS recommendations.	Formative	Retained
CMP5	I irrigate wheat as recommended under CRAPS.	Formative	Retained
TRT1	I trust my ability to implement CRAPSs on my wheat farm.	Reflective	Removed (duplicates PBC1)
TRT2	I trust CRAPSs because they increase productivity.	Reflective	Retained
TRT3	I believe that CRAPSs are reliable.	Reflective	Retained
TRT4	I believe that CRAPSs save time.	Reflective	Retained
ATT1	I am inclined to seek advice from agricultural experts about CRAPSs for my wheat farming.	Reflective	Removed (advice-seeking)
ATT2	I feel positive about using CRAPSs to reduce the impact of adverse climatic conditions on my wheat crop.	Reflective	Retained

Code	Item (5-point Likert, 1 = strongly disagree … 5 = strongly agree)	Specification	Status
ATT3	I have a positive attitude towards CRAPSs because they may help me adapt to changing climatic conditions in my area.	Reflective	Retained
SN1	Fellow farmers who are important to me think that I should use CRAPSs to increase income.	Reflective	Retained (injunctive norm)
SN2	Fellow farmers who are close to me think that I should learn more about CRAPSs for wheat.	Reflective	Retained (injunctive norm)
SN3	My fellow farmers are always willing to help me whenever I have difficulty with CRAPSs.	Reflective	Removed (social support)
SN4	People who influence my behaviour think that it is good to apply CRAPSs to wheat.	Reflective	Retained (injunctive norm)
PBC1	I feel confident in my ability to implement CRAPSs on my wheat farm.	Reflective	Retained (self-efficacy)
PBC2	I can manage the time to integrate CRAPSs into my wheat-farming activities.	Reflective	Retained (controllability)
PBC3	I can access relevant information and advice from extension staff to use	Reflective	Retained (controllability)
PBC4	It would be easy for me to manage my wheat crop with CRAPSs.	Reflective	Retained (ease)

Note: CRAPs = climate-resilient agricultural practice; INT = intention; CMP = current CRAPS management (past behaviour); TRT = trust in CRAPS performance; ATT = attitude; SN = subjective norms; PBC = perceived behavioural control. Item wording has been edited for grammar only; the meaning is identical to the questionnaire administered.
Nota: CRAPS = prática resiliente ao clima; INT = intenção; CMP = manejo atual de práticas resilientes ao clima (comportamento passado); TRT = confiança no desempenho das práticas resilientes ao clima; ATT = atitude; SN = normas subjetivas; PBC = controle comportamental percebido. A redação dos itens foi alterada apenas por questões gramaticais; o significado permanece idêntico ao do questionário aplicado.

3.5. Instrument development, translation and pre-testing

There were three sections of the questionnaire: Socio-economic characteristics, the psychometric scales and farm-level wheat data. The psychometric items are set up according to the structure recommended for TPB questionnaires (Ajzen, 1991; Fishbein; Ajzen, 2010), and are similar to items used in farm TPB studies (Wauters et al., 2010; Borges et al., 2014; Atta-Aidoo et al., 2022). The trust items reflect the reliability and performance aspects of technology trust (McKnight et al., 2011) and the management items reflect past behaviour (Ouellette; Wood, 1998) (Table 4). Five-point Likert scales (1 = strongly disagree; 5 = strongly agree) were used for all items. Interviews were conducted in Urdu or in Punjabi if the respondents preferred. The questionnaire was translated from English to Urdu and then back-translated independently by two bilingual experts, and differences arising from the two back translations were addressed by the research team.

To ensure the face and content validity, the panel of experts from the Department of Agricultural Sciences, Faculty of Sciences, Allama Iqbal Open University, Islamabad reviewed each item to decide its relevance to its construct and clarity; a few items were modified after their feedback. Furthermore, the questionnaire was individually examined for relevance and clarity of items by two Agriculture Officers in the public-sector agricultural extension service. A quantitative Content Validity Index was not calculated, which is a limitation. Cronbach's α for this original instrument was acceptable (0.76 overall). There were 7 experts on the panel. The instrument was pre-tested with 25 wheat growers from the non-sampled village of Kamoke Tehsil, and minor changes were made to the wording.

3.6. Measures and measurement-model specification

The items are listed in Table 4. After the content-validity critique of the original specification, each item was linked to the definition of the construct. There were five items judged to be measuring a concept different from the one they were supposed to measure, and thus were not included in the main model, as Table 4 demonstrates. ATT1 is a measure of advice-seeking, not evaluation. SN3 is not a measure of normative pressure; it is a measure of social support. TRT1 is a copy of PBC1 (self-efficacy). An attitude towards CRAPs and conventional practice is evaluated in INT1 and INT4. INT5 is a measure of intention to seek guidance NOT to implement. All original items are used in the model, which is reported as a robustness check (Model M1).

For each construct, it was determined whether the specification was reflective or formative (DIAMANTOPOULOS; WINKLHOFER, 2001; JARVIS et al., 2003). Attitude, subjective norms, PBC, trust and intention were defined as reflective (Mode A). In these constructs, it is assumed that the latent attitude or belief is the cause of the item responses, that the items are interchangeable expressions of one belief, that they are expected to covary and that dropping an item does not change the meaning of the construct. Current Climate management practices (CMP) was defined as formative (Mode B) as the five indicators refer to specific agronomic activities (land preparation, choice of variety, sowing, fertilisation and irrigation).

All these activities constitute a construct. They are not interchangeable, nor do they necessarily have to covary, and if one were removed (e.g., irrigation), the content of the construct would be changed. Hence, instead of AVE and reliability (Hair et al., 2022), indicator weights and their significance, indicator collinearity (VIF<3) and convergent (redundancy) validity (where possible) were evaluated for CMP. The reflective specification of CMP is shown as a sensitivity analysis for comparison.

3.7. Data collection and quality control

Six enumerators (M.Sc. (Hons) Agriculture graduates) were trained for three days on the instrument, consent procedure and neutral probing and face-to-face interviews were carried out by them; 10% of the completed interviews were back-checked by a field supervisor.

The interviews were approximately 35 minutes in length. Common method bias was minimised by assuring respondents' anonymity and by informing them that there were no right or wrong answers (PODSAKOFF et al., 2003).

The administered questionnaire included both intention items and outcome items; therefore, there was no procedural separation between predictor and outcome items. Statistical common method-bias checks are provided in the Results.

3.8. Ethical aspects

The study protocol was approved by the Ethical Review Committee, Faculty of Sciences, Allama Iqbal Open University, Islamabad (Approval No: AIOU/FS/ERC-2023/118, dated 20th November 2023). Prior to the interview, everyone was told the purpose of the study and that it was voluntary and that they could stop whenever they wanted without any repercussions.

As the population is illiterate, informed consent was obtained orally and recorded by the thumb impression of the person taking it (enumerator). No names or identifiers are kept with the responses, and data are provided in group form only.

3.9. Statistical analysis

Data were analysed using SPSS 27 and MS Excel and presented as descriptive statistics. The PLS-SEM model was estimated with the plssem package in Stata 14, and PLSpredict and the village-cluster bootstrap were computed with the seminr package in R (RAY et al., 2022). Four reasons were given for choosing PLS-SEM. The study's first goal is to predict intention and to extend an existing theory, which is the goal for which the use of PLS-SEM is recommended (HAIR et al., 2019). Second, there is a formatively specified construct (CMP) in the model. Third, the indicators are ordinal scores with a limited range of five points; multivariate normality was not possible. Fourth, the out-of-sample predictive performance can be evaluated using PLSpredict (SHMUELI et al., 2019). Sample size was not a reason for the choice.

With the algorithm, the path weighting scheme was used, 3000 iterations were run, and the stopping criterion was 10-7. Indicators were standardised (mean of 0 and variance of 1). All significance was evaluated by bootstrapping of 10000 subsamples with a two-tailed test at $\alpha = 0.05$, and percentile 95% confidence intervals (STREUKENS; LEROI-WERELDS, 2016). Exact p-values are reported. The questionnaires that were incomplete (11) were not analysed, and no values were missing in the 384 analysed questionnaires. Univariate ($|z| > 3.29$) and multivariate (Mahalanobis distance, $p < 0.001$) outliers were screened, and one case was flagged; results did not change after excluding this case.

The reflective measurement model was evaluated using outer loadings (preferred ≥ 0.708; between 0.40 and 0.708 retained if AVE and reliability were achieved), Cronbach's α, ρA and composite reliability ρc (preferred 0.70–0.95), and convergent validity (preferred AVE ≥ 0.50) (HAIR et al., 2019). Discriminant validity was evaluated by using the Fornell–Larcker criterion ($\sqrt{AVE}$ on the diagonal is greater than inter-construct correlations; Fornell; Larcker, 1981) and the heterotrait–monotrait ratio (HTMT < 0.85 and the bootstrap 95% upper bound < 1; Henseler et al., 2015).

Indicator VIFs, outer weights and loadings with bootstrap CIs (Hair et al., 2022) were used to evaluate the formative CMP construct. The following were reported for the structural model: predictor VIFs (< 3); standardised path coefficients with standard errors, t-statistics, exact p-values and 95% CIs; R^2 and adjusted R^2; f^2 effect sizes (0.02, 0.15 and 0.35 as small, medium and large); Q^2predict; and PLSpredict RMSE/MAE (compared with a linear-model benchmark) (SHMUELI et al., 2019). SRMR is reported for information only, as it is a questionable fit criterion in PLS-SEM (HAIR et al., 2019). The full-collinearity VIF approach and Harman's single-factor test (all VIFs < 3.3) were used to assess common-method bias (KOCK, 2015).

Robustness was evaluated using six alternative specifications: (M1) the original specification with all items and reflective CMP; (M2) the revised model (main model); (M3) the core TPB model without TRT and CMP to calculate the incremental R^2 (ΔR^2) of the extension; (M4) M2 with socio-economic controls (education, wheat area, experience) and district fixed effects; (M5) M2 with a cluster bootstrap in which villages, rather than individuals, were resampled, which accounts for within-village dependence (Cameron; Miller, 2015); and (M6) M2 without CMP, to test whether the sign of the CMP path are signs of suppression.

4. RESULTS

4.1. Participant flow and sample characteristics

Flow of the participants and characteristics of the sample The participant flow is summarised in Figure 3. The complete interviews of all 384 respondents were analysed. Respondents had a mean age of 49.1 years; 38.8% were 41–50 years old, and 27.6% were 40 or younger (Table 5; Figure 5). 85.2% of the respondents had some level of formal schooling with a mean of 5.92 years (SD = 4.29).

The school years of the graduates (aged 13 years or older) were coded according to the actual number of years of schooling (14–17 years). The mean experience with wheat farming was 21.3 years (range 1-42). The mean wheat area was 6.42 acres (2.60 ha), and 49.5% of growers had 5 acres (2.02 ha) or less. The average for wheat is 32.54 maunds $acre^{-1}$. One maund equals 40 kg, so this is 3.22 t ha^{-1}. The mean annual household income was PKR 1.26 million. Income for 58.1% of growers was from crop production and livestock.

4.2. Descriptive statistics of the constructs

All constructs (Table 6; Figure 6) had mean construct scores greater than the scale midpoint. They were highest for trust in CRAPS performance (4.03 ± 0.89) and current CRAPS management (3.99 ± 0.80), and lowest for attitude (3.48 ± 1.06) and intention (3.47 ± 1.07). These are means interpreting statements as being in agreement. They are not adoption rates, and a high mean does not equate to a strong predictor; that is a construct.

4.3. Measurement model

The measurement model is presented in Table 7. According to the original specification (M1), the AVE of intention and subjective norms, which were recomputed based on the reported standardised loadings, were below the 0.50 threshold, with values of 0.30 and 0.42, respectively. All five intention loadings (ranging between 0.51 and 0.61) were lower than 0.708, as was SN1 (0.41) (Figure 7). Convergent validity was therefore not achieved for these two constructs in M1. This prompted us to seek purification by content as described in the Methods (M2). In the revised model, all retained reflective loadings exceeded 0.708 (range 0.784–0.929; all $p < 0.001$); α, ρA and ρc ranged from 0.795 to 0.839, 0.795 to 0.840 and 0.880 to 0.918, respectively, and AVE

ranged from 0.647 to 0.849. Indicator VIFs for the formative CMP ranged from 1.529 to 1.709, and the outer weight of CMP5 (irrigation; w = 0.565, p = 0.001) was significant. The other four indicator weights were not significant (p = 0.247–0.511), but their loadings exceeded 0.50 (0.673–0.910; all p < 0.001), so all five indicators were retained (HAIR et al., 2022).

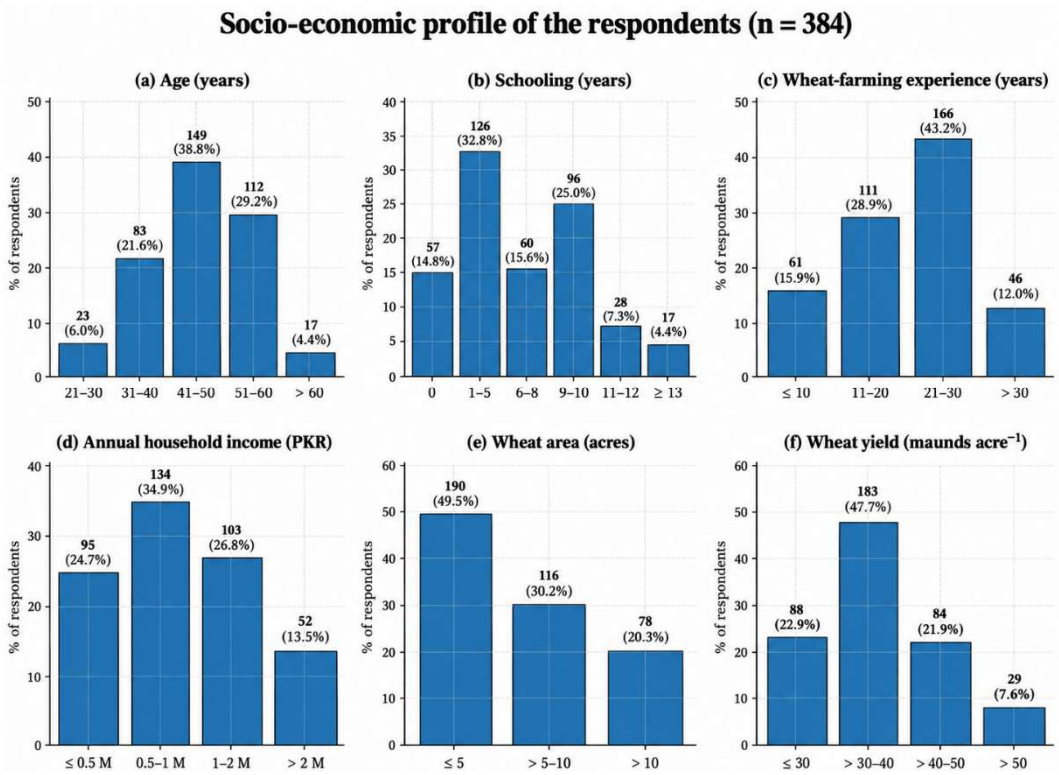


Figure 5. Socio-economic profile of the respondents (n = 384): (a) age, (b) schooling, (c) wheat-farming experience, (d) annual household income, (e) wheat area and (f) wheat yield (1 maund = 40 kg).
Figura 5. Perfil socioeconômico dos respondentes (n = 384): (a) idade, (b) escolaridade, (c) experiência no cultivo de trigo, (d) renda familiar anual, (e) área cultivada com trigo e (f) produtividade do trigo (1 maund = 40 kg).

Table 5. Socio-economic characteristics of the respondents (n = 384).
Tabela 5. Características socioeconômicas dos respondentes (n = 384).

Variable and class	Frequency	%	Mean (SD)
Age (years)			49.09 (11.16)
21–30	23	6.0	
31–40	83	21.6	
41–50	149	38.8	
51–60	112	29.2	
> 60	17	4.4	
Schooling (years)			5.92 (4.29)
0 (no formal schooling)	57	14.8	
1–5 (primary)	126	32.8	
6–8 (middle)	60	15.6	
9–10 (secondary)	96	25.0	
11–12 (higher secondary)	28	7.3	
≥ 13 (graduate and above)	17	4.4	
Wheat-farming experience (years)			21.32 (9.51)
≤ 10	61	15.9	
11–20	111	28.9	
21–30	166	43.2	
> 30	46	12.0	
Annual household income (PKR)			1,257,682 (897,611)
≤ 500,000	95	24.7	
500,001–1,000,000	134	34.9	
1,000,001–2,000,000	103	26.8	
> 2,000,000	52	13.5	

Variable and class	Frequency	%	Mean (SD)
Income source			
Crop cultivation only	97	25.3	
Crops plus livestock	223	58.1	
Multiple sources	64	16.7	
Wheat area, acres (ha)			6.42 (2.60 ha) (4.39)
≤ 5 (≤ 2.02)	190	49.5	
> 5–10 (> 2.02–4.05)	116	30.2	
> 10 (> 4.05)	78	20.3	
Wheat yield, maunds acre^{-1} (t ha^{-1})			32.54 (3.22 t ha^{-1}) (9.68)
≤ 30 (≤ 2.97)	88	22.9	
> 30–40 (> 2.97–3.95)	183	47.7	
> 40–50 (> 3.95–4.94)	84	21.9	
> 50 (> 4.94)	29	7.6	

Note: 1 maund = 40 kg; 1 acre = 0.4047 ha. Class limits are mutually exclusive and exhaustive. Percentages were recomputed from the frequencies (hence 15.6% and 26.8%, previously 15.7% and 26.9%). Values exactly on a class boundary (5 acres, 30 maunds, PKR 500,000) were coded in the lower class.
Nota: 1 maund = 40 kg; 1 acre = 0,4047 ha. Os limites das classes são mutuamente exclusivos e exaustivos. As porcentagens foram recalculadas a partir das frequências (daí 15,6% e 26,8%; anteriormente, 15,7% e 26,9%). Valores situados exatamente no limite de uma classe (5 acres, 30 maunds, 500.000 PKR) foram incluídos na classe inferior.

Table 6. Mean construct scores (1–5 scale).
Tabela 6. Médias dos escores dos construtos (escala de 1 a 5).

Construct	Mean	SD
Intention (INT)	3.465	1.065
Attitude (ATT)	3.477	1.055
Subjective norms (SN)	3.651	0.949
Perceived behavioural control	3.793	0.870
Trust in CRAPs performance	4.031	0.894
Current CRAPs management	3.986	0.799

4.4. Discriminant validity

Discriminant validity is shown in Table 8. The Fornell–Larcker criterion states that √AVE (diagonal) should be higher than the construct's correlation with other constructs (off-diagonal). Within the HTMT criterion, all ratios need to be less than 0.85, and their 95% upper boundaries of the bootstraps need to be less than 1. All HTMT ratios were < .85, with the highest ratio being ATT–INT of .751 (95% CI = .678 to .819), and all five reflective constructs met the Fornell–Larcker criterion. The correlation of attitude and intention (0.599) was higher than the √AVE of intention (0.549) in the original specification; thus, it was not satisfied in M1 for intention.

4.5. Collinearity and common-method bias

All inner-model VIFs were less than 3. In the original estimation, they ranged from 1.368 (TRT) to 2.195 (ATT) (Table 9), and in M2 they ranged from 1.655 to 2.266. Harman's single factor explained 46.1% of the variance (< 50%).

All full-collinearity VIFs were below 3.3 (1.658–2.653). Common method bias is therefore not likely to be a serious issue, although it cannot be ruled out by self-reported data from a single source (PODSAKOFF et al., 2003; KOCK, 2015).

Table 7. Measurement model: outer loadings, reliability and convergent validity.
Tabela 7. Modelo de mensuração: cargas externas, confiabilidade e validade convergente.

Statistic	INT	TRT	ATT	SN	PBC
Loadings (M1, as originally reported)	0.512–0.611	0.658–0.781	0.708–0.740	0.412–0.839	0.664–0.794
Cronbach's α (M1, as reported)	0.807*	0.821	0.706	0.708	0.712
ρA (M1, as reported)	0.710	0.821	0.772	0.733	0.741
ρc (M1, recomputed from loadings)	0.682	0.821	0.769	0.733	0.830
AVE (M1, recomputed from loadings)	0.301	0.535	0.527	0.421	0.551
√AVE (M1; value previously labelled "AVE")	0.549	0.732	0.726	0.649	0.743
Loadings, 95% CI (M2, revised)	0.911–0.920 [0.843–0.975]	0.846–0.898 [0.764–0.964]	0.913–0.929 [0.842–0.992]	0.812–0.857 [0.728–0.931]	0.784–0.824 [0.693–0.893]
Cronbach's α (M2)	0.807	0.839	0.822	0.795	0.818
ρA (M2)	0.807	0.840	0.822	0.795	0.819
ρc (M2)	0.912	0.903	0.918	0.880	0.880
AVE (M2)	0.838	0.757	0.849	0.709	0.647

Note: $\rho c = (\Sigma\lambda)^2/[(\Sigma\lambda)^2 + \Sigma(1 - \lambda^2)]$; AVE = $\Sigma\lambda^2/k$. *In M1, the reported α of 0.807 was not attainable with loadings of 0.51–0.61 (implied α ≈ 0.68); the re-estimated α of the revised two-item scale is 0.807. CMP (formative) is evaluated separately: indicator weights, loadings, VIFs and 95% CIs. Under a reflective specification (M1), CMP loadings were 0.729–0.810, ρc = 0.876 and AVE = 0.586.
Nota: $\rho c = (\Sigma\lambda)^2/[(\Sigma\lambda)^2 + \Sigma(1 - \lambda^2)]$; AVE = $\Sigma\lambda^2/k$. *No modelo M1, o valor de α de 0,807 relatado não era alcançável com cargas fatoriais entre 0,51 e 0,61 (α implícito ≈ 0,68); o valor de α reestimado para a escala revisada de dois itens é de 0,807. O construto CMP (formativo) é avaliado separadamente: os pesos dos indicadores, as cargas fatoriais, os VIFs e os intervalos de confiança (IC) de 95%. Sob uma especificação reflexiva (M1), as cargas fatoriais de CMP variaram de 0,729 a 0,810, com ρc = 0,876 e AVE = 0,586.



Figure 6. Mean construct scores (± 1 SD) of wheat growers on the 1–5 agreement scale. The dashed line marks the scale midpoint.
Figura 6. Médias dos escores dos construtos (± 1 DP) atribuídos pelos produtores de trigo em uma escala de concordância de 1 a 5. A linha tracejada indica o ponto médio da escala.

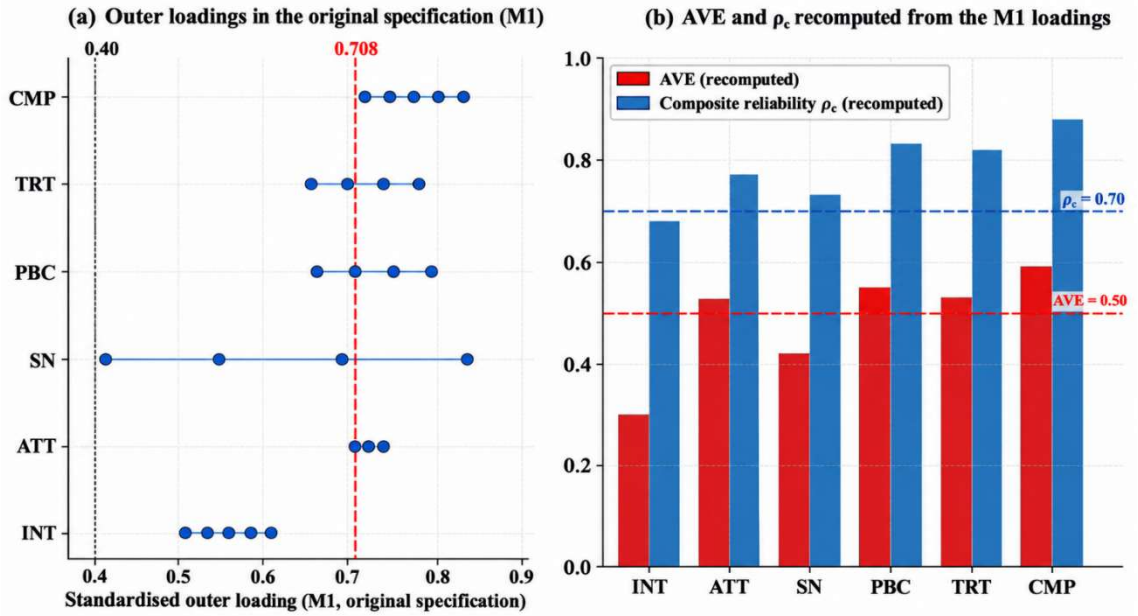


Figure 7. (a) Standardised outer loadings in the original specification (M1), with the 0.708 and 0.40 reference lines. (b) Average variance extracted (AVE) and composite reliability (ρc) recomputed from the loadings in (a), with the 0.50 (AVE) and 0.70 (ρc) thresholds. The revised-model (M2) values are in Table 7.
Figura 7. (a) Cargas externas padronizadas na especificação original (M1), com as linhas de referência em 0,708 e 0,40. (b) Variância média extraída (AVE) e confiabilidade composta (ρc) recalculadas a partir das cargas apresentadas em (a), com os limiares de 0,50 (para a AVE) e 0,70 (para a ρc). Os valores do modelo revisado (M2) encontram-se na Tabela 7.

4.6. Structural model

The structural model is shown in Table 9 and Figure 8. The largest positive standardized coefficient (β = 0.446) was found for attitude, thus supporting H1, as it was statistically significant at $p < 0.001$ and $f^2 = 0.171$. The second largest positive predictor was trust in CRAPS performance (β = 0.344; $p < 0.001$; $f^2 = 0.135$), supporting H4. PBC was positively associated with intention (β = 0.172; p = 0.001; $f^2 = 0.031$), supporting H3. Subjective norms were not significantly associated with intention (β = 0.038; p = 0.455; 95% CI −0.065 to 0.134), so H2 was not supported. Current CRAPS management was significantly negative ($p < 0.001$; f2 = 0.060; β = −0.246), contrary to the direction of the effect hypothesized in H5. It was positively correlated with

intention (zero-order = 0.253 in the original output and 0.335 in M2), and the sign change only occurred when PBC and trust were controlled. This pattern is explored in the robustness analysis below. The combined variance of the predictors accounted for was 48.6% of the variance in intention (R^2 = 0.486; adjusted R^2 = 0.479).

Table 8. Discriminant validity of the revised model (M2): Fornell–Larcker criterion (lower triangle; √AVE on the diagonal in bold) and HTMT ratios with bootstrap 95% CIs (upper triangle).
Tabela 8. Validade discriminante do modelo revisado (M2): critério de Fornell–Larcker (triângulo inferior; √AVE na diagonal, em negrito) e razões HTMT com intervalos de confiança (IC) de 95% via bootstrap (triângulo superior).

	ATT	SN	PBC	TRT	CMP	INT
ATT	**0.921**	0.739 (0.657–0.812)	0.721 (0.641–0.797)	0.677 (0.584–0.763)	–	0.751 (0.678–0.819)
SN	0.600	**0.842**	0.588 (0.495–0.673)	0.555 (0.449–0.651)	–	0.535 (0.429–0.635)
PBC	0.591	0.476	**0.805**	0.624 (0.525–0.712)	–	0.597 (0.506–0.683)
TRT	0.563	0.456	0.519	**0.870**	–	0.686 (0.602–0.765)
CMP	0.613	0.463	0.594	0.546	n/a (formative)	–
INT	0.613	0.430	0.486	0.567	0.335	**0.916**

Note: HTMT is not defined for formative constructs. ATT = attitude; SN = subjective norms; PBC = perceived behavioural control; TRT = trust in CRAPS performance; CMP = current CRAPS management; INT = intention.
Nota: O HTMT não é definido para construtos formativos. ATT = atitude; SN = normas subjetivas; PBC = controle comportamental percebido; TRT = confiança no desempenho do CRAPS; CMP = gestão atual do CRAPS; INT = intenção.

Table 9. Structural model results for intention (main model M2).
Tabela 9. Resultados do modelo estrutural para a intenção (modelo principal M2).

H	Path	B	SE	t	p	95% CI	f^2	VIF	Decision
H1	ATT → INT	0.446	0.057	7.82	< 0.001	0.319 to 0.543	0.171	2.266	Supported
H2	SN → INT	0.038	0.051	0.75	0.455	−0.065 to 0.134	0.002	1.655	Not supported
H3	PBC → INT	0.172	0.052	3.28	0.001	0.057 to 0.263	0.031	1.865	Supported
H4	TRT → INT	0.344	0.053	6.48	< 0.001	0.231 to 0.438	0.135	1.700	Supported
H5	CMP → INT	−0.246	0.066	−3.72	< 0.001	−0.323 to −0.068	0.060	1.958	Not supported (opposite sign)

Note: SE = bootstrap standard error; CI = percentile 95% confidence interval from 10,000 bootstrap subsamples; two-tailed tests.
Nota: EP = erro-padrão via bootstrap; IC = intervalo de confiança de 95% (método dos percentis) obtido a partir de 10.000 subamostras bootstrap; testes bicaudais.

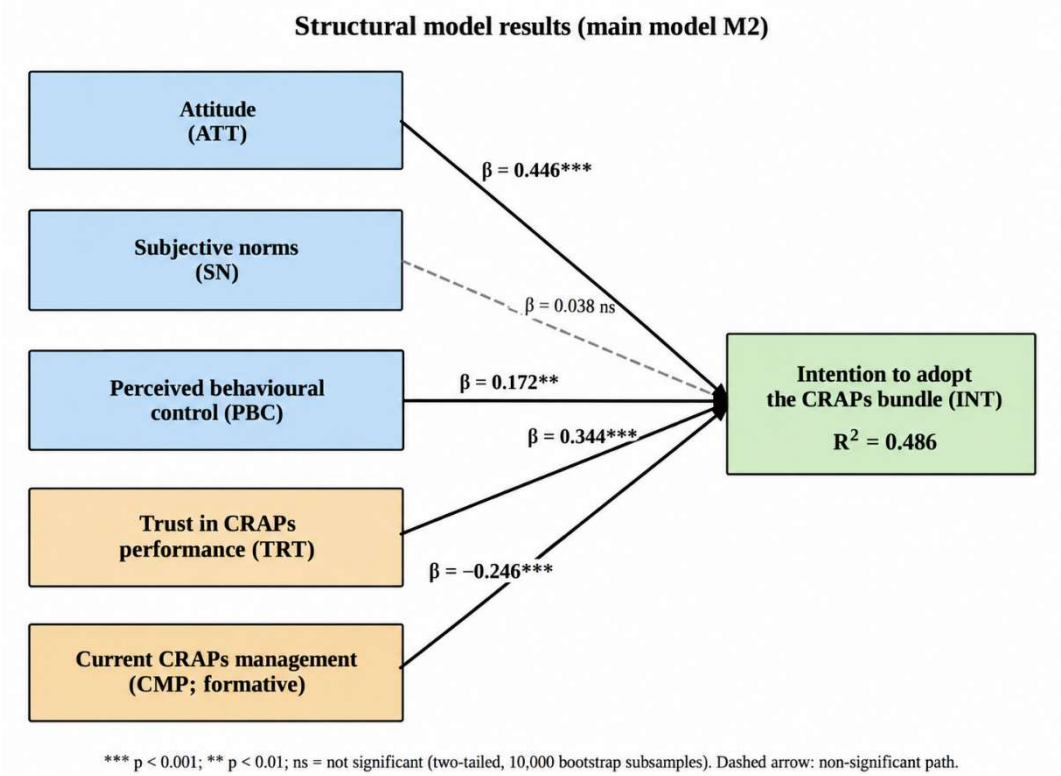


Figure 8. Structural model results: standardised path coefficients (β) and explained variance (R^2) of intention. Solid arrows show significant paths, and the dashed arrow shows a non-significant path. *** p < 0.001; ns = not significant (two-tailed, 10,000 bootstrap subsamples).
Figura 8. Resultados do modelo estrutural: coeficientes de trajetória padronizados (β) e variância explicada (R^2) da intenção. As setas contínuas indicam trajetórias significativas, e a seta tracejada, uma trajetória não significativa. *** p < 0,001; ns = não significativo (teste bicaudal, 10.000 subamostras de bootstrap).

4.7. Explanatory and predictive power

Explanatory and predictive power is reported in Table 10. The extension constructs (TRT and CMP) increased R^2 from 0.402 in the core TPB model (M3) to 0.486 in M2 (ΔR^2 = 0.084). Q2predict for intention was > 0 (0.389), which is predictive relevant. Both of the intention indicators in PLSpredict were found to be better than the linear-model benchmark, pointing towards medium to high predictive power (Figure 9; Shmueli et al., 2019). SRMR was 0.058.

4.8. Robustness analysis

Table 11 gives a summary of the alternative specifications. The five paths and their meanings were consistent from M1 to M6, with one exception below. The SN path was not significant in any of the specifications (β = 0.024 – 0.063). (ii) The CMP coefficient was still negative and significant when applied to the formative specification (M2), with the inclusion of socio-economic controls and district fixed effects (M4) and under the village-cluster bootstrap (M5; β = −0.246, 95% CI [−0.318, −0.064]).

As expected in the suppression interpretation, when CMP was removed (M6), the PBC coefficient was reduced to 0.101, and the TRT coefficient was reduced to 0.293. Attitude continued to be the most powerful predictor for all models. The use of the cluster bootstrap (m5) produced wider intervals in the village cluster, but did not alter any inferences. The ICC for the intention score across the 48 villages was 0.049 (effective n = 286), which is lower than the ICC of 0.10 that was assumed in the design-effect analysis (Table 11; Figure 10).

Table 10. Explanatory and predictive power of the core and extended models.
Tabela 10. Poder explicativo e preditivo dos modelos central e estendido.

Statistic	Core TPB (M3)	Extended (M2)	Δ (M2 − M3)
R^2 (INT)	0.402	0.486	0.084
Adjusted R^2 (INT)	0.397	0.479	0.082
Q^2predict (INT)	0.319	0.389	0.070
PLSpredict RMSE, PLS vs LM (INT2)	0.836 vs 0.844	0.796 vs 0.810	–
PLSpredict RMSE, PLS vs LM (INT3)	0.817 vs 0.823	0.769 vs 0.776	–
SRMR	0.065	0.058	–

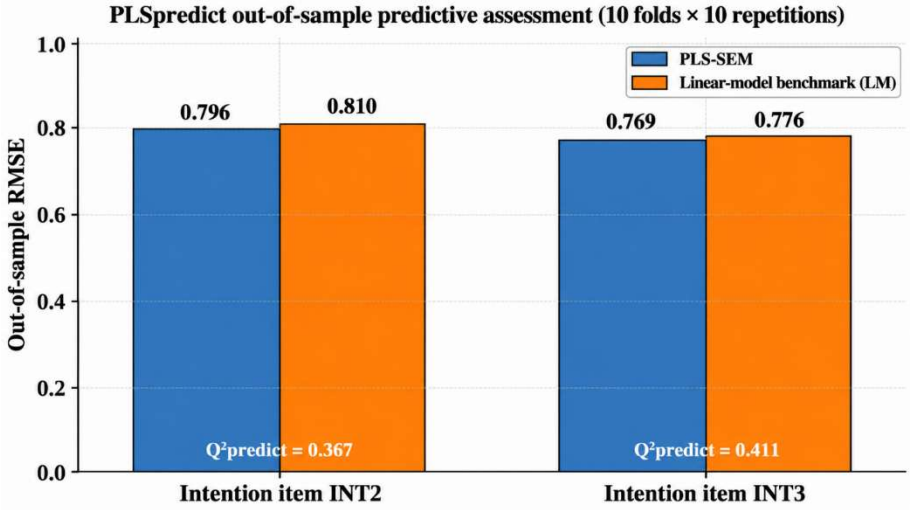


Figure 9. PLSpredict out-of-sample diagnostics for the extended model (M2): RMSE of the PLS-SEM model versus the linear model (LM) benchmark for the two retained intention indicators (10 folds × 10 repetitions).
Figura 9. Diagnósticos out-of-sample (fora da amostra) do PLSpredict para o modelo estendido (M2): RMSE do modelo PLS-SEM em comparação com o modelo linear (LM) de referência para os dois indicadores de intenção retidos (10 *folds* × 10 repetições).

Table 11. Robustness of the structural paths across alternative specifications (standardised β, with significance).
Tabela 11. Robustez dos caminhos estruturais em diferentes especificações (β padronizado, com significância).

Path	M1 original	M2 main	M3 core TPB	M4 + controls	M5 cluster bootstrap	M6 no CMP
ATT → INT	0.427***	0.446***	0.470***	0.444***	0.446***	0.374***
SN → INT	0.049 ns	0.038 ns	0.063 ns	0.042 ns	0.038 ns	0.024 ns
PBC → INT	0.176***	0.172**	0.178***	0.175***	0.172**	0.101*
TRT → INT	0.336***	0.344***	–	0.342***	0.344***	0.293***
CMP → INT	−0.247***	−0.246***	–	−0.239***	−0.246***	–
R^2 (INT)	0.505	0.486	0.402	0.501	0.486	0.455

Note: *** p < 0.001; ** p < 0.01; * p < 0.05; ns = not significant. M1 = all original items, CMP reflective; M2 = revised items, CMP formative; M3 = ATT, SN and PBC only; M4 = M2 plus education, wheat area, experience and district fixed effects; M5 = M2 with village-level cluster bootstrap; M6 = M2 without CMP.
Nota: *** p < 0,001; ** p < 0,01; * p < 0,05; ns = não significativo. M1 = todos os itens originais, CMP reflexivo; M2 = itens revisados, CMP formativo; M3 = apenas ATT, SN e PBC; M4 = M2 acrescido de escolaridade, área de cultivo de trigo, experiência e efeitos fixos por distrito; M5 = M2 com *bootstrap* por *cluster* no nível da localidade (*village*); M6 = M2 sem CMP.

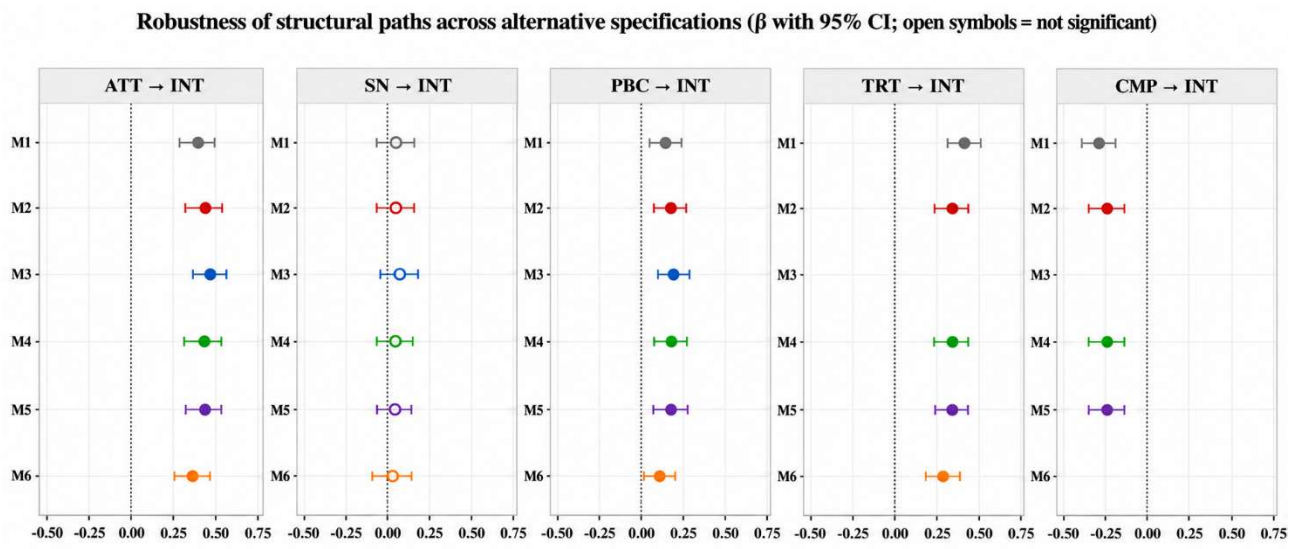


Figure 10. Robustness of the five structural paths across the six specifications (M1–M6): standardised coefficients with 95% bootstrap confidence intervals (percentile; village-cluster bootstrap for M5).
Figura 10. Robustez dos cinco caminhos estruturais nas seis especificações (M1–M6): coeficientes padronizados com intervalos de confiança de 95% obtidos por *bootstrap* (percentil; *bootstrap* por *cluster* de vilarejo no modelo M5).

5. DISCUSSION

Each hypothesis is discussed in turn in this section. It separates out associations that are not explicitly tested from those that are, and all implications are stated in terms of intention.

5.1. Attitude (H1)

Attitude was the greatest positive predictor of intention (β = 0.446; f^2 = 0.171). It is in line with meta-analytic findings indicating that attitude is typically the strongest TPB antecedent (ARMITAGE; CONNER, 2001). It also aligns with the farm studies on the practice of conservation and climate-smartness in Belgium, Mozambique and Ghana (Wauters et al., 2010; Lalani et al., 2016; Atta-Aidoo et al., 2022) and with the review by Sok et al. (2021). Growers who consider CRAPSs a benefit and desirable are more likely to report greater intentions to implement CRAPSs. Some of this overlap may be due to the overlap of content among the attitude items and the intention items, which was minimized but not eliminated by dropping INT1 and INT4. Common method variance may also play a role. In practical terms, communication that bolsters growers' assessments of CRAPSs could help increase intention. The design is cross-sectional, and this is an inferred recommendation to be evaluated through intervention studies.

5.2. Subjective norms (H2)

However, the results did not support H2, as subjective norms were not significantly related to intention when controlling for the other constructs (β = 0.038). The norm effects in TPB studies are often weak or not significant (Armitage; Conner, 2001) and in some farm studies (SOK et al., 2021). In other farms, however, the norm effects have been found to be significant (ATTA-AIDOO et al., 2022). The following explanations are only hypotheses and not part of this study. First, various aspects of the CRAPS (e.g. timing of fertiliser application and irrigation scheduling) are not readily visible to neighbours, potentially reducing the influence of norms (ROGERS, 2003). Second, the effect of normative influence might also be indirect and involve attitude, which correlated with SN (corr = 0.600 in M2). Third, the study had limited power to detect an effect of this size (Table 2). In future research, it is recommended to differentiate the injunctive from the descriptive norm and to examine the mediation of attitude.

5.3. Perceived behavioural control (H3)

The hypothesis was supported as PBC was positively related to intention (β = 0.172). This effect was lower than the effect of attitude, which is typical of farm TPB studies (Sok et al., 2021) and is more similar to the effect of climate-smart practices in Ghana (Atta-Aidoo et al., 2022) and that of technology in China (WANG et al., 2020). The PBC item are a mix of self-efficacy (PBC1, PBC4) and controllability (PBC2 time, PBC3 access to extension advice). The convergent validity of M2 indicates that these items can be treated as one dimension (0.647). This is in line with the idea that capacity-building and advice-giving can complement intention. It does not suggest that such support would make any difference in the level of adoption.

5.4. Perceptions of the effectiveness of CRAPs (H4)

There was a positive relationship between Trust in CRAPS performance and intention (β = 0.344). In addition to attitude, it was the second strongest predictor and contributed to a greater extent than the core TPB (ΔR^2 = 0.084). A high mean score (4.03) indicates that the majority of growers were positive towards the trust statements, but does not mean that trust is the most significant factor. The revised construct measures confidence in the reliability, productivity and time benefits of the practices (TRT2–TRT4). It is not designed to measure people's trust in extension agents or government institutions, and thus the findings are not valid for conclusions on institutional trust.

Conceptually, trust in CRAPS performance is similar to perceived benefits; the HTMT between TRT and ATT (0.677; 95% CI 0.584–0.763) should be taken into account when interpreting the unique contribution of ATT. This is consistent with evidence indicating that trust in the technology's performance reduces the perceived risk of trying

the technology (MEIJER et al., 2015; SIEGRIST, 2021). Therefore, field demonstrations to demonstrate CRAPS performance under local conditions are a plausible approach to extension, to be evaluated in future studies.

5.5. Current CRAPs management practices (H5)

However, the negative partial coefficient of current CRAPs management practices ($\beta = -0.246$) was contrary to the positive association suggested by the literature on past behaviours (OUELLETTE; WOOD, 1998). It should not be construed as resistance to change or to the traditional practice, as the CMP items are indicative of the current use of CRAPs components, not the feeling of attachment to conventional management. There are three alternative explanations that are consistent with the data. First, statistical suppression: CMP correlated positively with intention ($r = 0.335$) but strongly with PBC ($r = 0.594$) and trust ($r = 0.546$). It is thus possible that its negative partial coefficient is due to the variance it shares with these predictors and not to a negative impact of current practice.

The robustness model without CMP (M6) tests this explanation: the PBC and TRT coefficients decreased to 0.101 and 0.293, respectively, when CMP was removed (M6), supporting the shared-variance explanation. Second, a ceiling effect: growers who already practice most of the components have less room to "intend to adopt" the bundle, and their intention to change might be lower, even though their behaviour is already resilient. Third, item content: INT2 and INT3 indicate new effort and learning that may not seem as important to those who know it well. These explanations cannot be distinguished based on the data. Future studies should directly measure intention to continue and intention to expand CRAPS use, and model the past behaviour against the later behaviour in longitudinal designs.

5.6. Limitation and implications

Based on these qualifications, the results indicate three levels of caution for extension in the study area: (i) the need to increase the growers' awareness of the agronomic and economic value of CRAPs; (ii) the need to show growers the reliability of the CRAPs performance under the local conditions, for example, through farmer-field demonstrations; and (iii) the need to minimize the practical barriers to CRAPs, such as time and access to advice. Such recommendations are based on the stated intention to be associated with, and are not tested consequences of interventions.

Several limitations apply. The study has a cross-sectional design which does not allow causal inferences, and only intention to adopt is the final dependent variable; actual adoption was not measured. Common-method and social-desirability bias may have occurred as all data were self-reported from a single source. The first three sampling stages were purposive, as a result of which generalisation beyond the high wheat tehsils of the three zones studied is limited.

Growers also tended to be concentrated in villages, and this was dealt with using the design-effect analysis and the cluster bootstrap, but not with a full multilevel model. The aim behaviour was a set of five behaviours, and growers may have had varying intents for each behaviour. Lastly, there were some original items which lacked content validity. Although this issue is less problematic in the revised specification, future research is warranted using pre-validated, specially developed scales for injunctive norm, descriptive norm, technological and institutional trust, and component-specific intentions.

6. CONCLUSIONS

Intention to adopt a set of defined climate-smart practices was most related to attitude, then to labelled performance of the practices and perceived behavioural control among wheat growers of three agroecological zones of Punjab, which are high wheat-producing tehsils. There was no significant relationship between subjective norms and intention. In fact, current implementation of CRAPs components was negatively partially associated with intention, although it was positively bivariate associated with intention, seemingly a suppression or ceiling effect rather than a resistance to change.

With the inclusion of trust in technology performance, the TPB accounted for 0.084 additional variance in the overall model of the CRAPs ($\Delta R^2 = 0.084$) when compared to the model without this variable. Results also indicate that past behaviour can have different relationships with intention if the behaviour is partially adopted. Extension programmes can help reinforce intentions by showing how to perform CRAPs under local conditions, and by helping to build growers' capacity to implement.

These findings relate to stated intention and are based on a cross-sectional, self-reported and partially purposive sample with potential spatial dependence and common method bias. Future studies should track growers longitudinally to connect the intention with the adoption of each component of the CRAPS, and include the measurement of trust in institutions and in technology using specific scales, as well as the use of multilevel methods to model the effects of villages and districts.

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